

**ASME BOILER AND PRESSURE VESSEL CODE
AN INTERNATIONAL CODE**



NONDESTRUCTIVE EXAMINATION

**2001 Edition
July 1, 2001**

**ASME BOILER AND
PRESSURE VESSEL
COMMITTEE
SUBCOMMITTEE ON
NONDESTRUCTIVE
EXAMINATION**

**THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
NEW YORK, NEW YORK**

Date of Issuance: July 1, 2001
(Includes all Addenda dated July 2000 and earlier)

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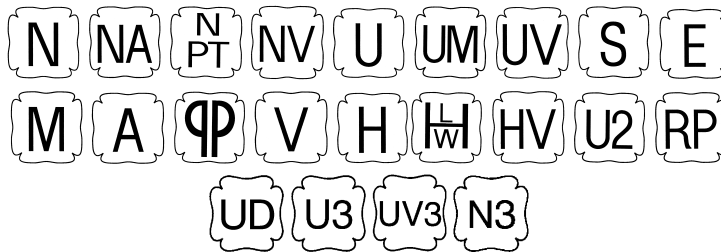
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Library of Congress Catalog Card Number: 56-3934
Printed in the United States of America

Adopted by the Council of the American Society of Mechanical Engineers, 1914.
Revised 1940, 1941, 1943, 1946, 1949, 1952, 1953, 1956, 1959, 1962, 1965, 1968, 1971, 1974, 1977, 1980, 1983, 1986, 1989, 1992, 1995, 1998, 2001

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2001 ASME

BOILER AND PRESSURE VESSEL CODE

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ADDENDA

Colored-sheet Addenda, which include additions and revisions to individual Sections of the Code, are published annually and will be sent automatically to purchasers of the applicable Sections up to the publication of the 2004 Code. The 2001 Code is available only in the loose-leaf format; accordingly, the Addenda will be issued in the loose-leaf, replacement-page format.

INTERPRETATIONS

ASME issues written replies to inquiries concerning interpretation of technical aspects of the Code. The Interpretations for each individual Section will be published separately and will be included as part of the update service to that Section. They will be issued semiannually (July and December) up to the publication of the 2004 Code. Interpretations of Section III, Divisions 1 and 2, will be included with the update service to Subsection NCA.

CODE CASES

The Boiler and Pressure Vessel Committee meets regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases which have been adopted will appear in the appropriate 2001 Code Cases book: (1) Boilers and Pressure Vessels and (2) Nuclear Components. Supplements will be sent automatically to the purchasers of the Code Cases books up to the publication of the 2004 Code.

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FOREWORD

The American Society of Mechanical Engineers set up a committee in 1911 for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels. This committee is now called the Boiler and Pressure Vessel Committee.

The Committee's function is to establish rules of safety governing the design, fabrication, and inspection during construction of boilers and pressure vessels, and to interpret these rules when questions arise regarding their intent. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of pressure vessels. The objective of the rules is to afford reasonably certain protection of life and property and to provide a margin for deterioration in service so as to give a reasonably long, safe period of usefulness. Advancements in design and material and the evidence of experience have been recognized.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction¹ activities. The Code does not address all aspects of these activities and those aspects which are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable designers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer

programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and they are responsible for the application of these programs to their design.

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practices as determined by the designer.

The Boiler and Pressure Vessel Committee deals with the care and inspection of boilers and pressure vessels in service only to the extent of providing suggested rules of good practice as an aid to owners and their inspectors.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Boiler and Pressure Vessel Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Boiler and Pressure Vessel Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Mandatory Appendix covering preparation of technical inquiries). Proposed revisions to the Code resulting from inquiries will be presented to the Main Committee for appropriate action. The action of the Main Committee becomes effective only after confirmation by letter ballot of the Committee and approval by ASME.

Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute and published in *Mechanical Engineering* to invite comments from all interested persons. After the allotted time for public review and final

¹Construction, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

approval by ASME, revisions are published annually in Addenda to the Code.

Code Cases may be used in the construction of components to be stamped with the ASME Code symbol beginning with the date of their approval by ASME.

After Code revisions are approved by ASME, they may be used beginning with the date of issuance shown on the Addenda. Revisions, except for revisions to material specifications in Section II, Parts A and B, become mandatory 6 months after such date of issuance, except for boilers or pressure vessels contracted for prior to the end of the 6 month period. Revisions to material specifications are originated by the American Society for Testing and Materials (ASTM), and other recognized national or international organizations and are usually adopted by ASME. However, those revisions may or may not have any effect on the suitability of material, produced to earlier editions of specifications, for use in ASME construction. ASME material specifications approved for use in each construction Code are listed in the Appendices of Section II, Parts A and B. These Appendices list, for each specification, the latest edition adopted by ASME, and earlier and later editions considered by ASME to be identical for ASME construction.

Manufacturers and users of components are cautioned against making use of revisions and Cases that are less restrictive than former requirements without having assurance that they have been accepted by the proper authorities in the jurisdiction where the component is to be installed.

Each state and municipality in the United States and each province in Canada that adopts or accepts one or more Sections of the Boiler and Pressure Vessel Code is invited to appoint a representative to act on the Conference Committee to the Boiler and Pressure Vessel Committee. Since the members of the Conference Committee are in active contact with the administration and enforcement of the rules, the requirements for inspection in this Code correspond with those in effect in their respective jurisdictions. The required qualifications for an Authorized Inspector under these rules may be obtained from the administrative authority of any state, municipality, or province which has adopted these rules.

The Boiler and Pressure Vessel Committee in the formulation of its rules and in the establishment of maximum design and operating pressures considers materials, construction, methods of fabrication, inspection, and safety devices. Permission may be granted to regulatory bodies and organizations publishing safety standards to use a complete Section of the Code by reference. If usage of a Section, such as Section IX,

involves exceptions, omissions, or changes in provisions, the intent of the Code might not be attained.

Where a state or other regulatory body, in the printing of any Section of the Boiler and Pressure Vessel Code, makes additions or omissions, it is recommended that such changes be clearly indicated.

The National Board of Boiler and Pressure Vessel Inspectors is composed of chief inspectors of states and municipalities in the United States and of provinces in Canada that have adopted the Boiler and Pressure Vessel Code. This Board, since its organization in 1919, has functioned to uniformly administer and enforce the rules of the Boiler and Pressure Vessel Code. The cooperation of that organization with the Boiler and Pressure Vessel Committee has been extremely helpful.

The Code Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The Scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules. Laws or regulations issued by municipality, state, provincial, federal, or other enforcement or regulatory bodies having jurisdiction at the location of an installation establish the mandatory applicability of the Code rules, in whole or in part, within their jurisdiction. Those laws or regulations may require the use of this Code for vessels or components not considered to be within its Scope or may establish additions or deletions in that Scope. Accordingly, inquiries regarding such laws or regulations are to be directed to the issuing enforcement or regulatory body.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the ASME Boiler and Pressure Vessel Committee. ASME is to be notified should questions arise concerning improper use of an ASME Code symbol.

The specifications for materials given in Section II are identical with or similar to those of the Specifications published by ASTM, AWS, and other recognized national or international organizations. When reference is made in an ASME material specification to a non-ASME specification for which a companion ASME specification exists, the reference shall be interpreted as applying to the ASME material specification. Not all materials included in the material specifications in Section II have been adopted for Code use. Usage is limited to those materials and grades adopted by at least one of the other Sections of the Code for application under rules of that Section. All materials allowed by these various Sections and used for construction

within the scope of their rules shall be furnished in accordance with material specifications contained in Section II or referenced in Appendices A of Section II, Parts A and B except where otherwise provided in Code Cases or in the applicable Section of the Code. Materials covered by these specifications are acceptable for use in items covered by the Code Sections only to the degree indicated in the applicable Section. Materials for Code use should preferably be ordered, produced, and documented on this basis; Appendix A to Section II, Part A and Appendix A to Section II, Part B list editions of ASME and year dates of specifications that meet ASME requirements and which may be used in Code construction. Material produced to an acceptable specification with requirements different from the requirements of the corresponding specifications listed in

Appendix A of Part A or Part B may also be used in accordance with the above, provided the material manufacturer or vessel manufacturer certifies with evidence acceptable to the Authorized Inspector that the corresponding requirements of specifications listed in Appendix A of Part A or Part B have been met. Material produced to an acceptable material specification is not limited as to country of origin.

When required by context in this Section, the singular shall be interpreted as the plural, and vice-versa; and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

Publication of the SI (Metric) Edition of the ASME Boiler and Pressure Vessel Code was discontinued with the 1986 Edition. Effective October 1, 1986, the SI Edition was withdrawn as an ASME Boiler and Pressure Vessel Code document.

STATEMENT OF POLICY ON THE USE OF CODE SYMBOLS AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use Code Symbols for marking items or constructions which have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the Code Symbols for the benefit of the users, the enforcement jurisdictions, and the holders of the symbols who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the symbols, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not “approve,” “certify,”

“rate,” or “endorse” any item, construction, or activity and there shall be no statements or implications which might so indicate. An organization holding a Code Symbol and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities “are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code,” or “meet the requirements of the ASME Boiler and Pressure Vessel Code.”

The ASME Symbol shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of a Code Symbol who may also use the facsimile in advertising to show that clearly specified items will carry the symbol. General usage is permitted only when all of a manufacturer’s items are constructed under the rules.

The ASME logo, which is the cloverleaf with the letters ASME within, shall not be used by any organization other than ASME.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the official Code Symbol Stamp described in the governing Section of the Code.

Markings such as “ASME,” “ASME Standard,” or any other marking including “ASME” or the various Code Symbols shall not be used on any item which is

not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME which tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

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E-7 ON NONDESTRUCTIVE TESTING

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The 2001 Edition of the Code contains both U.S. Customary and SI units. In all cases, the U.S. Customary units are the standard and SI units are provided for the convenience of the user.

SUMMARY OF CHANGES

The 2001 Edition of this Code contains revisions in addition to the 1998 Edition with 1999 and 2000 Addenda. The revisions are identified with the designation **01** in the margin and, as described in the Foreword, become mandatory six months after the publication date of the 2001 Edition. To invoke these revisions before their mandatory date, use the designation “2001 Edition” in documentation required by this Code. If you choose not to invoke these revisions before their mandatory date, use the designation “1998 Edition through the 2000 Addenda” in documentation required by this Code.

Changes given below are identified on the pages by a margin note, **01**, placed next to the affected area.

<i>Page</i>	<i>Location</i>	<i>Change</i>
12	Footnote 3	Corrected by Errata
16	Article 2 Contents	Updated to reflect 01
21	T-221.1	Title deleted and paragraph revised
24	T-272	Revised in its entirety
29	T-285	Note revised by Errata
	T-286	Last sentence corrected by Errata
44–45	VI-A-220	Title revised
	VI-A-230	Title revised
	VI-A-232.1	Title added
	VI-A-232.2	Title added
	VI-A-233	(1) Old VI-A-232.3 redesignated as VI-A-233 (2) Title added
	VI-A-234	(1) Old VI-A-232.4 redesignated as VI-A-234 (2) Title added
	VI-A-235	(1) Old VI-A-232.5 redesignated as VI-A-235 (2) Title added
	VI-A-240	Title revised
	VI-A-244	Paragraph references updated
63	T-423	New paragraph added
101	T-522	Title and paragraph revised
102	T-541.1	Subparagraphs (a)–(d) revised
	T-541.2	Subparagraphs (a) and (b) revised
103	T-541.3	Subparagraphs (a) and (b) revised
115	T-544(a), (b)	Cross-references revised
116	III-520	Subparagraph (c) corrected by Errata
122	T-610.1	Revised in its entirety
	T-621	Title revised
	T-621.1	Title deleted and paragraph revised
129	Article 7 Contents	Updated to reflect 01

<i>Page</i>	<i>Location</i>	<i>Change</i>
132	T-750	Revised in its entirety
137	T-778.1	Revised in its entirety
141	Appendix III	Added
147–148	T-810	Revised in its entirety
	T-821	Revised in its entirety
	T-822	Revised in its entirety
	T-823	Revised in its entirety
	Table T-823	Added
	T-830	Paragraph added
	T-831	Revised in its entirety
	T-832	Added
	T-833	Added
	T-850	Added
	T-861	Revised in its entirety
	T-862	Added
	T-870	Added
149	T-880	Paragraph added
	T-890	Paragraph T-881 revised and redesignated as T-890
	T-891	Added
	T-892	Added
157	II-860.1.1	Subparagraph (f) revised
160	III-810	Revised in its entirety
	III-822	Added
	III-823	Added
	III-850	Title revised
	III-851	Revised in its entirety
	III-852	(1) Old III-852 deleted (2) Old III-853 redesignated as III-852
161	III-890	Revised in its entirety
	III-891	Added
	III-892	Added
164–165	T-910	Revised in its entirety
	T-921	Revised in its entirety
	T-922	Added
	T-923	Added
	Table T-923	Added
	T-930	Added
	T-940	Title revised
	T-941	Title revised
	T-941.1	Revised in its entirety
	T-950	Title revised
	T-952	Revised in its entirety
166	T-954	Last sentence deleted
	T-980.2	Revised
	T-990	Title revised
	T-991	Revised in its entirety
	T-992	(1) New T-992 added

<i>Page</i>	<i>Location</i>	<i>Change</i>
		(2) Old T-992 redesignated as T-993
167	I-920	(1) Definition for <i>lux</i> added (2) Revised
173	T-1010	(1) Titles for Appendices IX and X added (2) Appendix references updated
	T-1021	Revised
	T-1031	Revised
174	T-1040	Title revised
	T-1050	Title revised
	T-1052	Revised in its entirety
	T-1063.1	Revised
177–180	I-1080	Revised in its entirety
	II-1080	Revised in its entirety
	III-1061	Revised in its entirety
	III-1062	Revised
	III-1063	Revised
	III-1064	(1) New III-1064 added (2) Old III-1064 revised and redesignated as III-1065
181–184	III-1077	Revised
	III-1078.2	Revised
	III-1080	Revised in its entirety
	IV-1061.2	Revised in its entirety
	IV-1061.3	Deleted
	IV-1062.1	Revised in its entirety
	IV-1062.2	Revised in its entirety
	IV-1062.3	Revised in its entirety
	IV-1062.4	(1) Old IV-1062.4 deleted (2) Old IV-1062.5 redesignated as IV-1062.4
	IV-1073	Revised
	IV-1077	Revised
	IV-1078.2	Revised
	IV-1080	Revised in its entirety
	Appendix V	Appendix title revised
	V-1010	Revised in its entirety
	V-1031	Revised
	V-1032	(1) Subparagraph (e) deleted (2) Subparagraph (f) redesignated as (e)
	V-1033	Revised in its entirety
	V-1061.2	Revised in its entirety
	V-1062.1	Revised
	V-1062.2	(1) New title added (2) Subparagraph revised
	V-1062.3	(1) New title added (2) Subparagraph revised
	V-1062.4	Added
	V-1062.5	Old V-1062.2 redesignated as V-1062.5
	V-1071	(1) Old V-1071 deleted (2) Old V-1071.1 revised and redesignated as V-1071

<i>Page</i>	<i>Location</i>	<i>Change</i>
	V-1072	(1) Old V-1072 Deleted (2) Old V-1071.2 revised and redesignated as V-1072
	V-1073	Old V-1071.3 revised and redesignated as V-1073
	V-1074	Old V-1071.4 revised and redesignated as V-1074
	V-1075	Added
	V-1080	Revised in its entirety
186	VII-1020	Revised in its entirety
	VII-1030	Paragraph designator deleted
188	VIII-1061	Revised
	VIII-1062	Revised
	VIII-1063	Revised
	VIII-1064	(1) New VIII-1064 added (2) Old VIII-1064 revised and redesignated as VIII-1065
189	VIII-1077	Revised
	VIII-1078.2	Revised
	VIII-1080	Revised in its entirety
190	Appendix IX	Added
193	Appendix X	Added
195	A-10	Revised in its entirety
199	T-1128	Title and paragraph revised
223	T-1225	Title and paragraph revised
247	T-1350	Title and paragraph revised
264	Article 22 Contents	Updated to reflect 01
280	SE-142	Deleted
281	SE-186	Deleted
282	SE-242	Deleted
283	SE-280	Deleted
284	SE-446	Deleted
365	SE-1647	Updated to reflect ASTM E 1647-98a
444	Article 24 Contents	Updated to reflect 01
489	SE-1209	Deleted
490	SE-1219	Deleted
491	SE-1220	Deleted
536	Article 26 Contents	Updated to reflect 01
537	SE-215	Deleted
545	SE-309	Deleted
546	SE-426	Deleted
547	SE-571	Deleted
601	Article 30 Contents	Updated to reflect 01
602	SE-1316	Updated to reflect ASTM E 1316-99

Subsection A

**Nondestructive Methods
of Examination**

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ARTICLE 1

GENERAL REQUIREMENTS

T-110 SCOPE

(a) Unless otherwise specified by the referencing Code Section or other referencing documents, this Section of the Code contains requirements and methods for nondestructive examination which are Code requirements to the extent they are specifically referenced and required by other Code Sections. These nondestructive examination methods are intended to detect surface and internal discontinuities in materials, welds, and fabricated parts and components. They include radiographic examination, ultrasonic examination, liquid penetrant examination, magnetic particle examination, eddy current examination, visual examination, leak testing, and acoustic emission examination.

(b) For general terms such as *Inspection*, *Flaw*, *Discontinuity*, *Evaluation*, etc., refer to Mandatory Appendix I.

T-120 GENERAL

(a) Subsection A describes the methods of nondestructive examination to be used if referenced by other Code Sections.

(b) Subsection B lists Standards covering nondestructive examination methods which have been accepted as standards. These standards are intended to be informative only and are nonmandatory unless specifically referenced in whole or in part in Subsection A or as indicated in other Code Sections.

(c) Reference to a paragraph of any Article in Subsection A of this Section or in the referencing Code Section includes all of the applicable rules in the paragraph.¹ In every case, reference to a paragraph includes all the subparagraphs and subdivisions under that paragraph.

(d) Reference to a Standard contained in Subsection B is mandatory only to the extent specified in an

¹For example, reference to T-270 includes all the rules contained in T-271 through T-277.3.

Article of Subsection A or as specified in other Code Sections.²

T-130 EQUIPMENT

It is the responsibility of the Manufacturer, fabricator, or installer to ensure that the examination equipment being used conforms to the requirements of this Code Section.

T-140 REQUIREMENTS

(a) Nondestructive Examination Personnel shall be qualified in accordance with the requirements of the referencing Code Section.

(b) For those Code Sections that directly reference this Article for the qualification of NDE personnel, the qualification shall be in accordance with one of the following documents:

(1) SNT-TC-1A,³ Personnel Qualification and Certification in Nondestructive Testing; or

(2) ANSI/ASNT CP-189,³ ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel; or

(3) ACCP,³ ASNT Central Certification Program.

(c) When the referencing Code Section does not specify qualifications or does not reference directly Article 1 of this Section, qualification may simply involve demonstration in routine manufacturing operations to show that the personnel performing the nonde-

²For example, T-233 requires that Image Quality Indicators be manufactured and identified in accordance with the requirements or alternatives allowed in SE-747 or SE-1025, and Appendices, as appropriate for the style of IQI to be used. These are the only parts of either SE-747 or SE-1025 that are mandatory in Article 2.

³SNT-TC-1A (1996 Edition, with 1998 Addendum), "Personnel Qualification and Certification in Nondestructive Testing;" ANSI/ASNT CP-189 (1995 Edition), "ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel;" and ACCP [Revision 3 (November 1997)], "ASNT Central Certification Program;" published by the American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, Ohio 43228-0518.

structive examinations are competent to do so in accordance with the Manufacturer's established procedures.

(d) The certificate holder shall ensure that NDE personnel are qualified and certified in accordance with this Article. The certificate holder's Quality Program shall stipulate how this is to be accomplished.

(e) Qualifications in accordance with a prior edition of SNT-TC-1A, CP-189, or ACCP are valid until recertification. Recertification or new certification shall be in accordance with the edition of SNT-TC-1A, CP-189, or ACCP specified in footnote 3.

(f) Limited certification of nondestructive examination personnel who do not perform all of the operations of a nondestructive method that consists of more than one operation, or who perform nondestructive examinations of limited scope, may be based on fewer hours of training and experience than recommended in SNT-TC-1A, CP-189, or ACCP. Any limitations or restrictions placed upon a person's certification shall be described in the written practice and on the certification.

(g) The SNT-TC-1A document is a guide to establish practices for training, qualification, and certification of NDE personnel as required by the referencing Code Section.

T-150 PROCEDURE

(a) The nondestructive examination methods included in this Section are applicable to most geometric configurations and materials encountered in fabrication under normal conditions. However, special configurations and materials may require modified methods and techniques, in which case the Manufacturer shall develop special procedures which are equivalent or superior to the methods and techniques described in this Code Section, and which are capable of producing interpretable examination results under the special conditions. Such special procedures may be modifications or combinations of methods described or referenced in this Code Section, and shall be proved by demonstration to be capable of detecting discontinuities under the special conditions, and such demonstrated capabilities shall be equivalent to the capabilities of the methods described in this Code Section when used under more general conditions. Depending on the quality assurance or quality control system requirements of the referencing Code Section, these special procedures shall be submitted to the Inspector for acceptance where required, and shall be adopted as part of the Manufacturer's quality control program.

(b) When an examination to the requirements of this Section of the Code is required by other Sections of the

Code, it shall be the responsibility of the Manufacturer, fabricator, or installer to establish nondestructive examination procedures and personnel certification procedures conforming to the referencing Code requirements.

(c) When required by the referencing Code Section, all nondestructive examinations performed under this Code Section shall be done to a written procedure. This procedure shall be demonstrated to the satisfaction of the Inspector. The procedure or method shall comply with the applicable requirements of this Section for the particular examination method. Where so required, written procedures shall be made available to the Inspector on request. At least one copy of each procedure shall be readily available to the Manufacturer's Nondestructive Examination Personnel for their reference and use.

T-160 CALIBRATION

(a) The Manufacturer, fabricator, or installer shall assure that all equipment calibrations required by Subsection A and/or Subsection B are performed.

(b) When special procedures are developed [see T-150(a)], the Manufacturer, fabricator, or installer shall specify what calibration is necessary, when calibration is required.

T-170 EXAMINATIONS AND INSPECTIONS

(a) The Inspector concerned with the fabrication of the vessel or pressure part shall have the duty of verifying to his satisfaction that all examinations required by the referencing Code Section have been made to the requirements of this Section and the referencing Code Section. He shall have the right to witness any of these examinations to the extent stated in the referencing Code Section. Throughout this Section of the Code, the word *Inspector* means the *Authorized Inspector* who has been qualified as required in the various referencing Code Sections.

(b) The special distinction established in the various Code Sections between *inspection* and *examination* and the personnel performing them is also adopted in this Code Section. In other words, the term *inspection* applies to the functions performed by the *Authorized Inspector*, but the term *examination* applies to those quality control functions performed by personnel employed by the Manufacturer. One area of occasional deviation from these distinctions exists. In the ASTM Standard Methods and Recommended Practices incorpo-

rated in this Section of the Code by reference or by reproduction in Subsection B, the words *inspection* or *Inspector*, which frequently occur in the text or titles of the referenced ASTM documents, may actually describe what the Code calls *examination* or *examiner*. This situation exists because ASTM has no occasion to be concerned with the distinctions which the Code makes between *inspection* and *examination*, since ASTM activities and documents do not involve the *Authorized Inspector* described in the Code Sections. However, no attempt has been made to edit the ASTM documents to conform with Code usage; this should cause no difficulty if the users of this Section recognize that the terms *inspection*, *testing*, and *examination* in the ASTM documents referenced in Subsection B do not describe duties of the *Authorized Code Inspector* but rather

describe the things to be done by the Manufacturer's *examination* personnel.

T-180 EVALUATION

The acceptance standards for these methods shall be as stated in the referencing Code Section.

T-190 RECORDS/DOCUMENTATION

Records/Documentation shall be in accordance with the referencing Code Section and the applicable requirements of Subsection A and/or B of this Code Section. The Manufacturer, fabricator, or installer shall be responsible for all required Records/Documentation.

ARTICLE 1

MANDATORY APPENDIX

APPENDIX I — GLOSSARY OF TERMS FOR NONDESTRUCTIVE EXAMINATION

I-110 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definition of terms common to all methods used in Nondestructive Examination.

I-120 GENERAL REQUIREMENTS

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 Section A provides the definition of terms listed in I-130(a).

(c) Paragraph I-130(b) provides a list of terms and definitions, which are in addition to SE-1316 and are Code specific.

I-130 REQUIREMENTS

(a) The following SE-1316 terms are used in conjunction with this Article: *defect, discontinuity, evaluation, false indication, flaw, flaw characterization, imperfection, interpretation, nonrelevant indication, relevant indication*.

(b) The following Code terms are used in conjunction with this Article:

area of interest — the specific portion of the object that is to be evaluated as defined by the referencing Code Section

indication — the response or evidence from a nondestructive examination that requires interpretation to determine relevance

inspection — the observation of any operation performed on materials and/or components to determine its acceptability in accordance with given criteria

limited certification — an accreditation of an individual's qualification to perform some but not all of the operations within a given nondestructive examination method or technique that consists of one or more than one operation, or to perform nondestructive examinations within a limited scope of responsibility

method — the following is a list of nondestructive examination methods and respective abbreviations used within the scope of Section V:

RT — Radiography

UT — Ultrasonics

MT — Magnetic Particle

PT — Liquid Penetrants

VT — Visual

LT — Leak Testing

ET — Electromagnetic (Eddy Current)

AE — Acoustic Emission

nondestructive examination (NDE) — the development and application of technical methods to examine materials and/or components in ways that do not impair future usefulness and serviceability in order to detect, locate, measure, interpret, and evaluate flaws

operation — a specific phase of a method or technique

procedure — an orderly sequence of actions describing how a specific technique shall be applied

sensitivity — a measure of the level of response from a discontinuity by a nondestructive examination

technique — a technique is a specific way of utilizing a particular nondestructive examination (NDE) method

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ARTICLE 2

RADIOGRAPHIC EXAMINATION

T-210 SCOPE

The radiographic method described in this Article for examination of materials including castings and welds shall be used together with Article 1, General Requirements. Definitions of terms used in this Article are in Mandatory Appendix V of this Article.

Certain product-specific, technique-specific, and application-specific requirements are also given in other Mandatory Appendices of this Article, as listed in the table of contents. These additional requirements shall also be complied with when an Appendix is applicable to the radiographic or radioscopy examination being conducted.

T-220 GENERAL REQUIREMENTS

T-221 Procedure Requirements

01 T-221.1 Radiographic examination shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable:

- (a) material type and thickness range,
- (b) isotope or maximum X-ray voltage used,
- (c) minimum source-to-object distance,
- (d) maximum distance from source side of object to the film,
- (e) maximum source size,
- (f) film brand and designation, and
- (g) screens used.

T-221.2 **Procedure Demonstration.** Demonstration of the density and IQI image requirements of the written procedure on production or technique radiographs shall be considered satisfactory evidence of compliance with that procedure.

T-222 Surface Preparation

T-222.1 **Materials Including Castings.** Surfaces shall satisfy the requirements of the applicable materials specification or referencing Code Section, with addi-

tional conditioning, if necessary, by any suitable process to such a degree that the resulting radiographic image due to any surface irregularities cannot mask or be confused with the image of any discontinuity.

T-222.2 **Welds.** The weld ripples or weld surface irregularities on both the inside (where accessible) and outside shall be removed by any suitable process to such a degree that the resulting radiographic image due to any surface irregularities cannot mask or be confused with the image of any discontinuity.

The finished surface of all butt-welded joints may be flush with the base material or may have reasonably uniform crowns, with reinforcement not to exceed that specified in the referencing Code Section.

T-223 Backscatter Radiation

A lead symbol "B," with minimum dimensions of $\frac{1}{2}$ in. (13 mm) in height and $\frac{1}{16}$ in. (1.6 mm) in thickness, shall be attached to the back of each film holder during each exposure to determine if backscatter radiation is exposing the film.

T-224 System of Identification

A system shall be used to produce permanent identification on the radiograph traceable to the contract, component, weld or weld seam, or part numbers, as appropriate. In addition, the Manufacturer's symbol or name and the date of the radiograph shall be plainly and permanently included on the radiograph. This identification system does not necessarily require that the information appear as radiographic images. In any case, this information shall not obscure the area of interest.

T-225 Monitoring Density Limitations of Radiographs

Either a densitometer or step wedge comparison film shall be used for judging film density.

T-226 Extent of Examination

The extent of radiographic examination shall be as specified by the referencing Code Section.

Testing SE-94 shall be used as a guide for processing film.

T-230 EQUIPMENT AND MATERIALS**T-231 Film**

T-231.1 Selection. Film selection shall be in accordance with SE-1815, Standard Test Method for Film Systems for Industrial Radiography. The film manufacturer shall determine the film system class for the family of films manufactured and provide a classification table. A typical Film Classification Table is as shown in SE-1815, Table 1. Film system classes Special, I, II, III, W-A, and W-B are permitted.

Caution — If any of the film processing parameters are changed from those provided by the film manufacturer, the class may not be valid, in which case the film manufacturer should be contacted for further guidance.

T-231.2 Processing. Standard Guide for Controlling the Quality of Industrial Radiographic Film Processing, SE-999, or Part III of Standard Guide for Radiographic

T-232 Intensifying Screens

Intensifying screens may be used when performing radiographic examination in accordance with this Article.

T-233 Image Quality Indicator (IQI) Design

IQIs shall be either the hole type or the wire type. Hole-type IQIs shall be manufactured and identified in accordance with the requirements or alternates allowed in SE-1025. Wire-type IQIs shall be manufactured and identified in accordance with the requirements or alternates allowed in SE-747, except that the largest wire number or the identity number may be omitted. ASME standard IQIs shall consist of those in Table T-233.1 for hole type and those in Table T-233.2 for wire type.

TABLE T-233.1
HOLE-TYPE IQI DESIGNATION, THICKNESS, AND HOLE DIAMETERS

IQI Designation, in. (mm)	IQI Thickness, in. (mm)	1 T Hole Diameter, in. (mm)	2 T Hole Diameter, in. (mm)	4 T Hole Diameter, in. (mm)
5	0.005 (0.13)	0.010 (0.25)	0.020 (0.51)	0.040 (1.02)
7	0.0075 (0.19)	0.010 (0.25)	0.020 (0.51)	0.040 (1.02)
10	0.010 (0.25)	0.010 (0.25)	0.020 (0.51)	0.040 (1.02)
12	0.0125 (0.32)	0.0125 (0.32)	0.025 (0.64)	0.050 (1.27)
15	0.015 (0.38)	0.015 (0.38)	0.030 (0.76)	0.060 (1.52)
17	0.0175 (0.44)	0.0175 (0.44)	0.035 (0.89)	0.070 (1.78)
20	0.020 (0.51)	0.020 (0.51)	0.040 (1.02)	0.080 (2.03)
25	0.025 (0.64)	0.025 (0.64)	0.050 (1.27)	0.100 (2.54)
30	0.030 (0.76)	0.030 (0.76)	0.060 (1.52)	0.120 (3.05)
35	0.035 (0.89)	0.035 (0.89)	0.070 (1.78)	0.140 (3.56)
40	0.040 (1.02)	0.040 (1.02)	0.080 (2.03)	0.160 (4.06)
45	0.045 (1.14)	0.045 (1.14)	0.090 (2.29)	0.180 (4.57)
50	0.050 (1.27)	0.050 (1.27)	0.100 (2.54)	0.200 (5.08)
60	0.060 (1.52)	0.060 (1.52)	0.120 (3.05)	0.240 (6.10)
70	0.070 (1.78)	0.070 (1.78)	0.140 (3.56)	0.280 (7.11)
80	0.080 (2.03)	0.080 (2.03)	0.160 (4.06)	0.320 (8.13)
100	0.100 (2.54)	0.100 (2.54)	0.200 (5.08)	0.400 (10.16)
120	0.120 (3.05)	0.120 (3.05)	0.240 (6.10)	0.480 (12.19)
140	0.140 (3.56)	0.140 (3.56)	0.280 (7.11)	0.560 (14.22)
160	0.160 (4.06)	0.160 (4.06)	0.320 (8.13)	0.640 (16.26)
200	0.200 (5.08)	0.200 (5.08)	0.400 (10.16)	...
240	0.240 (6.10)	0.240 (6.10)	0.480 (12.19)	...
280	0.280 (7.11)	0.280 (7.11)	0.560 (14.22)	...

TABLE T-233.2
WIRE IQI DESIGNATION, WIRE DIAMETER,
AND WIRE IDENTITY

Set A			Set B		
Wire Diameter, in.	(mm)	Wire Identity	Wire Diameter, in.	(mm)	Wire Identity
0.0032	(0.08)	1	0.010	(0.25)	6
0.004	(0.01)	2	0.013	(0.33)	7
0.005	(0.13)	3	0.016	(0.41)	8
0.0063	(0.16)	4	0.020	(0.51)	9
0.008	(0.20)	5	0.025	(0.64)	10
0.010	(0.25)	6	0.032	(0.81)	11

Set C			Set D		
Wire Diameter, in.	(mm)	Wire Identity	Wire Diameter, in.	(mm)	Wire Identity
0.032	(0.81)	11	0.100	(2.54)	16
0.040	(1.02)	12	0.126	(3.20)	17
0.050	(1.27)	13	0.160	(4.06)	18
0.063	(1.60)	14	0.200	(5.08)	19
0.080	(2.03)	15	0.250	(6.35)	20
0.100	(2.54)	16	0.320	(8.13)	21

T-234 Facilities for Viewing of Radiographs

Viewing facilities shall provide subdued background lighting of an intensity that will not cause troublesome reflections, shadows, or glare on the radiograph. Equipment used to view radiographs for interpretation shall provide a variable light source sufficient for the essential IQI hole or designated wire to be visible for the specified density range. The viewing conditions shall be such that light from around the outer edge of the radiograph or coming through low-density portions of the radiograph does not interfere with interpretation.

T-260 CALIBRATION

T-261 Source Size

T-261.1 Verification of Source Size. The equipment manufacturer's or supplier's publications, such as technical manuals, decay curves, or written statements documenting the actual or maximum source size or focal spot, shall be acceptable as source size verification.

T-261.2 Determination of Source Size. When manufacturer's or supplier's publications are not available, source size may be determined as follows:

(a) *X-Ray Machines.* For X-ray machines operating at 500 kV and less, the focal spot size may be determined by the pinhole method,¹ or in accordance with SE-1165, Standard Test Method for Measurement of Focal Spots of Industrial X-Ray Tubes by Pinhole Imaging.

(b) *Iridium-192 Sources.* For Iridium-192, the source size may be determined in accordance with SE-1114, Standard Test Method for Determining the Focal Size of Iridium-192 Industrial Radiographic Sources.

T-262 Densitometer and Step Wedge Comparison Film

T-262.1 Densitometers. Densitometers shall be calibrated at least every 90 days during use as follows:

(a) A national standard step tablet or a step wedge calibration film, traceable to a national standard step tablet and having at least 5 steps with neutral densities from at least 1.0 through 4.0, shall be used. The step wedge calibration film shall have been verified within the last year by comparison with a national standard step tablet.

(b) The densitometer manufacturer's step-by-step instructions for the operation of the densitometer shall be followed.

(c) The density steps closest to 1.0, 2.0, 3.0, and 4.0 on the national standard step tablet or step wedge calibration film shall be read.

(d) The densitometer is acceptable if the density readings do not vary by more than ± 0.05 density units from the actual density stated on the national standard step tablet or step wedge calibration film.

T-262.2 Step Wedge Comparison Films. Step wedge comparison films shall be verified prior to first use, unless performed by the manufacturer, as follows:

(a) The density of the steps on a step wedge comparison film shall be verified by a calibrated densitometer.

(b) The step wedge comparison film is acceptable if the density readings do not vary by more than ± 0.1 density units from the density stated on the step wedge comparison film.

T-262.3 Periodic Verification

(a) *Densitometers.* Periodic calibration verification checks shall be performed as described in T-262.1 at the beginning of each shift, after 8 hr of continuous use, or after change of apertures, whichever comes first. The densitometer is acceptable if the density

¹ Nondestructive Testing Handbook, Volume I, First Edition, pp. 14.32–14.33, "Measuring Focal-Spot Size." Also, pp. 20–21 of *Radiography in Modern Industry*, Fourth Edition.

readings are within ± 0.05 of the calibration readings determined in T-262.1(c).

(b) *Step Wedge Comparison Films.* Verification checks shall be performed annually per T-262.2.

T-262.4 Documentation

(a) Densitometer calibration readings required by T-262.1(c) shall be recorded in an appropriate calibration log.

(b) Periodic verification readings required by T-262.3 do not have to be recorded.

T-270 EXAMINATION

T-271 Radiographic Technique²

A single-wall exposure technique shall be used for radiography whenever practical. When it is not practical to use a single-wall technique, a double-wall technique shall be used. An adequate number of exposures shall be made to demonstrate that the required coverage has been obtained.

T-271.1 Single-Wall Technique. In the single-wall technique, the radiation passes through only one wall of the weld (material), which is viewed for acceptance on the radiograph.

T-271.2 Double-Wall Technique. When it is not practical to use a single-wall technique, one of the following double-wall techniques shall be used.

(a) *Single-Wall Viewing.* For materials and for welds in components, a technique may be used in which the radiation passes through two walls and only the weld (material) on the film-side wall is viewed for acceptance on the radiograph. When complete coverage is required for circumferential welds (materials), a minimum of three exposures taken 120 deg. to each other shall be made.

(b) *Double-Wall Viewing.* For materials and for welds in components $3\frac{1}{2}$ in. (89 mm) or less in nominal outside diameter, a technique may be used in which the radiation passes through two walls and the weld (material) in both walls is viewed for acceptance on the same radiograph. For double-wall viewing, only a source-side IQI shall be used. Care should be exercised to ensure that the required geometric unsharpness is not exceeded. If the geometric unsharpness requirement cannot be met, then single-wall viewing shall be used.

(1) For welds, the radiation beam may be offset from the plane of the weld at an angle sufficient to

separate the images of the source-side and film-side portions of the weld so that there is no overlap of the areas to be interpreted. When complete coverage is required, a minimum of two exposures taken 90 deg. to each other shall be made for each joint.

(2) As an alternative, the weld may be radiographed with the radiation beam positioned so that the images of both walls are superimposed. When complete coverage is required, a minimum of three exposures taken at either 60 deg. or 120 deg. to each other shall be made for each joint.

(3) Additional exposures shall be made if the required radiographic coverage cannot be obtained using the minimum number of exposures indicated in (b)(1) or (b)(2) above.

T-272 Radiation Energy

01

The radiation energy employed for any radiographic technique shall achieve the density and IQI image requirements of this Article.

T-273 Direction of Radiation

The direction of the central beam of radiation should be centered on the area of interest whenever practical.

T-274 Geometric Unsharpness

Geometric unsharpness of the radiograph shall be determined in accordance with:

$$Ug = Fd/D$$

where

Ug = geometric unsharpness

F = source size: the maximum projected dimension of the radiating source (or effective focal spot) in the plane perpendicular to the distance D from the weld or object being radiographed, in.

D = distance from source of radiation to weld or object being radiographed, in.

d = distance from source side of weld or object being radiographed to the film

NOTE: Refer to Standard Guide for Radiographic Testing SE-94 for a method of determining geometric unsharpness. Alternatively, a nomograph as shown in Standard Guide for Radiographic Testing SE-94 may be used.

T-275 Location Markers

Location markers (see Fig. T-275), which are to appear as radiographic images on the film, shall be

² Sketches showing suggested source, film, and IQI placements for pipe or tube welds are illustrated in Article 2, Nonmandatory Appendix A.

placed on the part, not on the exposure holder/cassette. Their locations shall be permanently marked on the surface of the part being radiographed when permitted, or on a map, in a manner permitting the area of interest on a radiograph to be accurately traceable to its location on the part, for the required retention period of the radiograph. Evidence shall also be provided on the radiograph that the required coverage of the region being examined has been obtained. Location markers shall be placed as follows.

T-275.1 Single-Wall Viewing

(a) *Source-Side Markers.* Location markers shall be placed on the source side when radiographing the following:

- (1) flat components or longitudinal joints in cylindrical or conical components;
- (2) curved or spherical components whose concave side is toward the source and when the “source-to-material” distance is less than the inside radius of the component;
- (3) curved or spherical components whose convex side is toward the source.

(b) Film-Side Markers

(1) Location markers shall be placed on the film side when radiographing either curved or spherical components whose concave side is toward the source and when the “source-to-material” distance is greater than the inside radius.

(2) As an alternative to source-side placement in T-275.1(a)(1), location markers may be placed on the film side when the radiograph shows coverage beyond the location markers to the extent demonstrated by Fig. T-275, sketch (e), and when this alternate is documented in accordance with T-291.

(c) *Either Side Markers.* Location markers may be placed on either the source side or film side when radiographing either curved or spherical components whose concave side is toward the source and the “source-to-material” distance equals the inside radius of the component.

T-275.2 Double-Wall Viewing. For double-wall viewing, at least one location marker shall be placed adjacent to the weld (or on the material in the area of interest) for each radiograph.

T-275.3 Mapping the Placement of Location Markers. When inaccessibility or other limitations prevent the placement of markers as stipulated in T-275.1 and T-275.2, a dimensioned map of the actual marker placement shall accompany the radiographs to show that full coverage has been obtained.

T-276 IQI Selection

T-276.1 Material. IQIs shall be selected from either the same alloy material group or grade as identified in SE-1025 or from an alloy material group or grade with less radiation absorption than the material being radiographed.

T-276.2 Size. The designated hole IQI or essential wire shall be as specified in Table T-276. A thinner or thicker hole-type IQI may be substituted for any section thickness listed in Table T-276, provided an equivalent IQI sensitivity is maintained. See T-283.2.

(a) *Welds With Reinforcements.* The thickness on which the IQI is based is the nominal single-wall thickness plus the estimated weld reinforcement not to exceed the maximum permitted by the referencing Code Section. Backing rings or strips shall not be considered as part of the thickness in IQI selection. The actual measurement of the weld reinforcement is not required.

(b) *Welds Without Reinforcements.* The thickness on which the IQI is based is the nominal single-wall thickness. Backing rings or strips shall not be considered as part of the weld thickness in IQI selection.

T-276.3 Welds Joining Dissimilar Materials or Welds With Dissimilar Filler Metal. When the weld metal is of an alloy group or grade that has a radiation attenuation that differs from the base material, the IQI material selection shall be based on the weld metal and be in accordance with T-276.1. When the density limits of T-282.2 cannot be met with one IQI, and the exceptional density area(s) is at the interface of the weld metal and the base metal, the material selection for the additional IQIs shall be based on the base material and be in accordance with T-276.1.

T-277 Use of IQIs to Monitor Radiographic Examination

T-277.1 Placement of IQIs

(a) *Source-Side IQI(s).* The IQI(s) shall be placed on the source side of the part being examined, except for the condition described in T-277.1(b).

When, due to part or weld configuration or size, it is not practical to place the IQI(s) on the part or weld, the IQI(s) may be placed on a separate block. Separate blocks shall be made of the same or radiographically similar materials (as defined in SE-1025) and may be used to facilitate IQI positioning. There is no restriction on the separate block thickness, provided the IQI/area-of-interest density tolerance requirements of T-282.2 are met.

Fig. T-275

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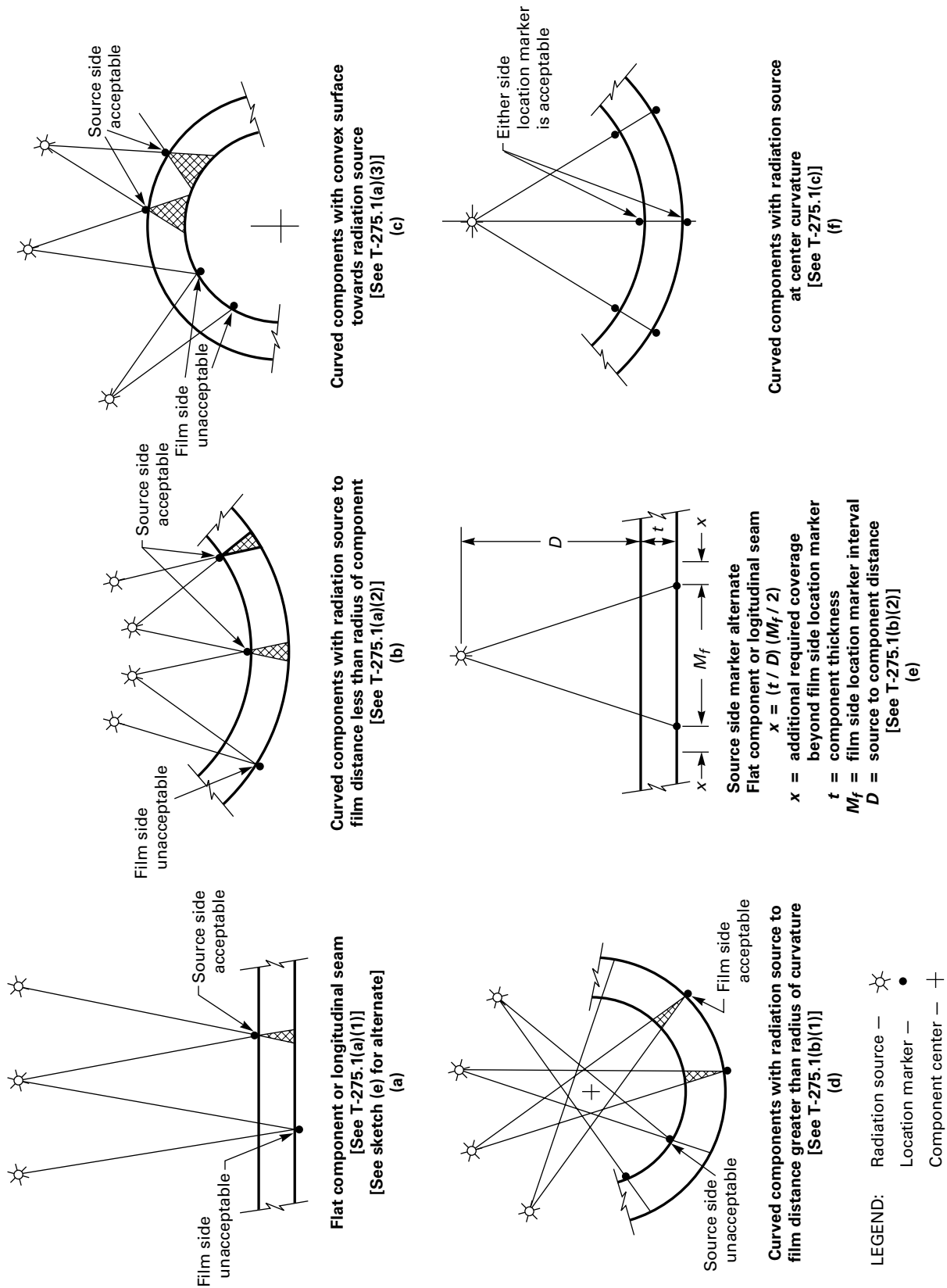


FIG. T-275 LOCATION MARKER SKETCHES

TABLE T-276
IQI SELECTION

Nominal Single-Wall Material Thickness Range		IQI			
		Source Side		Film Side	
		Hole-Type Designation	Wire-Type Essential Wire	Hole-Type Designation	Wire-Type Essential Wire
in.	mm				
Up to 0.25, incl.	Up to 6.4, incl.	12	5	10	4
Over 0.25 through 0.375	Over 6.4 through 9.5	15	6	12	5
Over 0.375 through 0.50	Over 9.5 through 12.7	17	7	15	6
Over 0.50 through 0.75	Over 12.7 through 19.0	20	8	17	7
Over 0.75 through 1.00	Over 19.0 through 25.4	25	9	20	8
Over 1.00 through 1.50	Over 25.4 through 38.1	30	10	25	9
Over 1.50 through 2.00	Over 38.1 through 50.8	35	11	30	10
Over 2.00 through 2.50	Over 50.8 through 63.5	40	12	35	11
Over 2.50 through 4.00	Over 63.5 through 101.6	50	13	40	12
Over 4.00 through 6.00	Over 101.6 through 152.4	60	14	50	13
Over 6.00 through 8.00	Over 152.4 through 203.2	80	16	60	14
Over 8.00 through 10.00	Over 203.2 through 254.0	100	17	80	16
Over 10.00 through 12.00	Over 254.0 through 304.8	120	18	100	17
Over 12.00 through 16.00	Over 304.8 through 406.4	160	20	120	18
Over 16.00 through 20.00	Over 406.4 through 508.0	200	21	160	20

(1) The IQI on the source side of the separate block shall be placed no closer to the film than the source side of the part being radiographed.

(2) The separate block shall be placed as close as possible to the part being radiographed.

(3) The block dimensions shall exceed the IQI dimensions such that the outline of at least three sides of the IQI image shall be visible on the radiograph.

(b) *Film-Side IQI(s)*. Where inaccessibility prevents hand placing the IQI(s) on the source side, the IQI(s) shall be placed on the film side in contact with the part being examined. A lead letter “F” shall be placed adjacent to or on the IQI(s), but shall not mask the essential hole where hole IQIs are used.

(c) *IQI Placement for Welds — Hole IQIs*. The IQI(s) may be placed adjacent to or on the weld. The identification number(s) and, when used, the lead letter “F,” shall not be in the area of interest, except when geometric configuration makes it impractical.

(d) *IQI Placement for Welds — Wire IQIs*. The IQI(s) shall be placed on the weld so that the length of the wires is perpendicular to the length of the weld. The identification numbers and, when used, the lead letter “F,” shall not be in the area of interest, except when geometric configuration makes it impractical.

(e) *IQI Placement for Materials Other Than Welds*. The IQI(s) with the IQI identification number(s), and,

when used, the lead letter “F,” may be placed in the area of interest.

T-277.2 Number of IQIs. When one or more film holders are used for an exposure, at least one IQI image shall appear on each radiograph except as outlined in (b) below.

(a) *Multiple IQIs*. If the requirements of T-282 are met by using more than one IQI, one shall be representative of the lightest area of interest and the other the darkest area of interest; the intervening densities on the radiograph shall be considered as having acceptable density.

(b) *Special Cases*³

(1) For cylindrical components where the source is placed on the axis of the component for a single exposure, at least three IQIs, spaced approximately 120 deg. apart, are required under the following conditions:

(a) When the complete circumference is radiographed using one or more film holders, or;

(b) When a section or sections of the circumference, where the length between the ends of the outermost sections span 240 or more deg., is radiographed using one or more film holders. Additional film locations may be required to obtain necessary IQI spacing.

³ Refer to Nonmandatory Appendix D for additional guidance.

(2) For cylindrical components where the source is placed on the axis of the component for a single exposure, at least three IQIs, with one placed at each end of the span of the circumference radiographed and one in the approximate center of the span, are required under the following conditions:

(a) When a section of the circumference, the length of which is greater than 120 deg. and less than 240 deg., is radiographed using just one film holder, or;

(b) When a section or sections of the circumference, where the length between the ends of the outermost sections span less than 240 deg., is radiographed using more than one film holder.

(3) In (1) and (2) above, where sections of longitudinal welds adjoining the circumferential weld are radiographed simultaneously with the circumferential weld, an additional IQI shall be placed on each longitudinal weld at the end of the section most remote from the junction with the circumferential weld being radiographed.

(4) For spherical components where the source is placed at the center of the component for a single exposure, at least three IQIs, spaced approximately 120 deg. apart, are required under the following conditions:

(a) When a complete circumference is radiographed using one or more film holders, or;

(b) When a section or sections of a circumference, where the length between the ends of the outermost sections span 240 or more deg., is radiographed using one or more film holders. Additional film locations may be required to obtain necessary IQI spacing.

(5) For spherical components where the source is placed at the center of the component for a single exposure, at least three IQIs, with one placed at each end of the radiographed span of the circumference radiographed and one in the approximate center of the span, are required under the following conditions:

(a) When a section of a circumference, the length of which is greater than 120 deg. and less than 240 deg., is radiographed using just one film holder, or;

(b) When a section or sections of a circumference, where the length between the ends of the outermost sections span less than 240 deg. is radiographed using more than one film holder.

(6) In (4) and (5) above, where other welds are radiographed simultaneously with the circumferential weld, one additional IQI shall be placed on each other weld.

(7) When an array of components in a circle is radiographed, at least one IQI shall show on each component image.

(8) In order to maintain the continuity of records involving subsequent exposures, all radiographs exhibiting IQIs that qualify the techniques permitted in accordance with (1) through (6) above shall be retained.

T-277.3 Shims Under Hole IQIs. For welds, a shim of material radiographically similar to the weld metal shall be placed between the part and the IQI, if needed, so that the radiographic density throughout the area of interest is no more than minus 15% from (lighter than) the radiographic density through the IQI.

The shim dimensions shall exceed the IQI dimensions such that the outline of at least three sides of the IQI image shall be visible in the radiograph.

T-280 EVALUATION

T-281 Quality of Radiographs

All radiographs shall be free from mechanical, chemical, or other blemishes to the extent that they do not mask and are not confused with the image of any discontinuity in the area of interest of the object being radiographed. Such blemishes include, but are not limited to:

- (a) fogging;
- (b) processing defects such as streaks, watermarks, or chemical stains;
- (c) scratches, finger marks, crimps, dirtiness, static marks, smudges, or tears;
- (d) false indications due to defective screens.

T-282 Radiographic Density

T-282.1 Density Limitations. The transmitted film density through the radiographic image of the body of the appropriate hole IQI or adjacent to the designated wire of a wire IQI and the area of interest shall be 1.8 minimum for single film viewing for radiographs made with an X-ray source and 2.0 minimum for radiographs made with a gamma ray source. For composite viewing of multiple film exposures, each film of the composite set shall have a minimum density of 1.3. The maximum density shall be 4.0 for either single or composite viewing. A tolerance of 0.05 in density is allowed for variations between densitometer readings.

T-282.2 Density Variation

(a) *General.* If the density of the radiograph anywhere through the area of interest varies by more than minus 15% or plus 30% from the density through the body of the hole IQI or adjacent to the designated wire of a wire IQI, within the minimum/maximum allowable

TABLE T-283
EQUIVALENT HOLE-TYPE IQI SENSITIVITY

Hole-Type Designation 2T Hole	Equivalent Hole-Type Designations	
	1T Hole	4T Hole
10	15	5
12	17	7
15	20	10
17	25	12
20	30	15
25	35	17
30	40	20
35	50	25
40	60	30
50	70	35
60	80	40
80	120	60
100	140	70
120	160	80
160	240	120
200	280	140

density ranges specified in T-282.1, then an additional IQI shall be used for each exceptional area or areas and the radiograph retaken. When calculating the allowable variation in density, the calculation may be rounded to the nearest 0.1 within the range specified in T-282.1.

(b) *With Shims.* When shims are used the plus 30% density restriction of (a) above may be exceeded, provided the required IQI sensitivity is displayed and the density limitations of T-282.1 are not exceeded.

T-283 IQI Sensitivity

T-283.1 Required Sensitivity. Radiography shall be performed with a technique of sufficient sensitivity to display the designated hole IQI image and the 2T hole, or the essential wire of a wire IQI. The radiographs shall also display the IQI identifying numbers and letters. If the designated hole IQI image and 2T hole, or essential wire, do not show on any film in a multiple film technique, but do show in composite film viewing, interpretation shall be permitted only by composite film viewing.

T-283.2 Equivalent Hole-Type Sensitivity. If a thinner or thicker hole-type IQI than listed in Table T-276 was substituted, an equivalent IQI sensitivity, as specified in Table T-283, shall have been maintained as well as all other requirements for radiography having been met.

T-284 Excessive Backscatter

If a light image of the “B,” as described in T-223, appears on a darker background of the radiograph, protection from backscatter is insufficient and the radiograph shall be considered unacceptable. A dark image of the “B” on a lighter background is not cause for rejection.

T-285 Geometric Unsharpness Limitations

01

Geometric unsharpness of the radiograph shall not exceed the following:

Material Thickness, in. (mm)	U_g Maximum, in. (mm)
Under 2 (50.8)	0.020 (0.51)
2 through 3 (50.8–76.2)	0.030 (0.76)
Over 3 through 4 (76.2–101.6)	0.040 (1.02)
Greater than 4 (101.6)	0.070 (1.78)

NOTE: Material thickness is the thickness on which the IQI is based.

T-286 Evaluation by Manufacturer

01

The Manufacturer shall be responsible for the review, interpretation, evaluation, and acceptance of the completed radiographs to assure compliance with the requirements of Article 2 and the referencing Code Section. As an aid to the review and evaluation, the radiographic technique documentation required by T-291 shall be completed prior to the evaluation. The radiograph review form required by T-292 shall be completed during the evaluation. The radiographic technique details and the radiograph review form documentation shall accompany the radiographs. Acceptance shall be completed prior to presentation of the radiographs and accompanying documentation to the Inspector.

T-290 DOCUMENTATION

T-291 Radiographic Technique Documentation Details

The Manufacturer shall prepare and document the radiographic technique details. As a minimum, the following information shall be provided.

(a) identification, e.g., job/contract number and heat number (if applicable)

(b) the dimensional map (if used) of marker placement in accordance with T-275.3

(c) number of radiographs (exposures)

(d) X-ray voltage or isotope type used

(e) X-ray machine focal spot size or isotope physical sources size

(f) base material type and thickness, weld thickness, weld reinforcement thickness, as applicable

(g) minimum source-to-object distance

(h) maximum distance from source side of object to the film

(i) film manufacturer and Manufacturer's type/designation

(j) number of film in each film holder/cassette

(k) single- or double-wall exposure

(l) single- or double-wall viewing

T-292 Radiograph Review Form

The Manufacturer shall prepare a radiograph review form. As a minimum, the following information shall be provided.

(a) a listing of each radiograph location

(b) the information required in T-291, by inclusion or by reference

(c) evaluation and disposition of the material(s) or weld(s) examined

(d) identification (name) of the Manufacturer's representative who performed the final acceptance of the radiographs

(e) date of Manufacturer's evaluation

ARTICLE 2

MANDATORY APPENDIX

APPENDIX I — IN-MOTION RADIOGRAPHY

I-210 SCOPE

In-motion radiography is a technique of radiography where the object being radiographed and/or the source of radiation is in motion during the exposure.

In-motion radiography may be performed on weldments when the following modified provisions to those in Article 2 are satisfied.

I-220 GENERAL REQUIREMENTS

I-223 Backscatter Detection Symbol Location

(a) For longitudinal welds the lead symbol “B” shall be attached to the back of each film cassette or at approximately equal intervals not exceeding 36 in. (914 mm) apart, whichever is smaller.

(b) For circumferential welds, the lead symbol “B” shall be attached to the back of the film cassette in each quadrant or spaced no greater than 36 in. (914 mm), whichever is smaller.

I-260 CALIBRATION

I-263 Beam Width

The beam width shall be controlled by a metal diaphragm such as lead. The diaphragm for the energy selected shall be at least 10 half value layers thick.

The beam width as shown in Fig. I-263 shall be determined in accordance with:

$$w = \frac{c(F + a)}{b} + a$$

where

w = beam width at the source side of the weld measured in the direction of motion

a = slit width in diaphragm in direction of motion

b = distance from source to the weld side of the diaphragm

c = distance from weld side of the diaphragm to the source side of the weld surface

F = source size: the maximum projected dimension of the radiating source (or focal spot) in the plane perpendicular to the distance $b + c$ from the weld being radiographed

NOTE: Use consistent units.

I-270 EXAMINATION

I-274 Geometric and In-Motion Unsharpness

I-274.1 Geometric Unsharpness. Geometric unsharpness for an in-motion radiograph shall be determined as specified in T-274.

I-274.2 In-Motion Unsharpness. In-motion unsharpness of the radiograph shall be determined in accordance with:

$$U_M = \frac{wd}{D}$$

where

U_M = in-motion unsharpness

w = beam width at the source side of the weld measured in the direction of motion determined as specified in I-263

d = distance from source side of the weld being radiographed to the film

D = distance from source of radiation to weld being radiographed

NOTE: Use consistent units

I-275 Location Markers

Location markers shall be placed adjacent to the weld at the extremity of each film cassette and

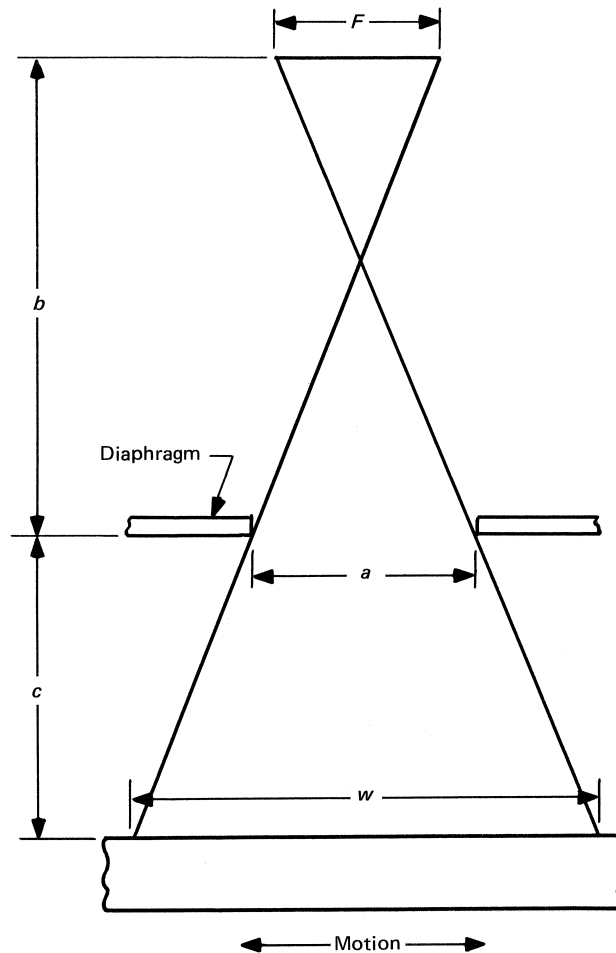


FIG. I-263

also at approximately equal intervals not exceeding 15 in. (381 mm).

I-277 Placement and Number of IQIs

(a) For longitudinal welds, hole IQIs shall be placed adjacent to and on each side of the weld seam, or on the weld seam at the beginning and end of the weld seam, and thereafter at approximately equal intervals not exceeding 36 in. (914 mm) or for each film cassette. Wire IQIs, when used, shall be placed on the weld seam so that the length of the wires is perpendicular to the length of the weld and spaced as indicated above for hole IQIs.

(b) For circumferential welds, hole IQIs shall be placed adjacent to and on each side of the weld seam or on the weld seam in each quadrant or spaced no greater than 36 in. (914 mm) apart, whichever is smaller.

Wire IQIs, when used, shall be placed on the weld seam so that the length of the wires is perpendicular to the length of the weld and spaced as indicated above for hole IQIs.

I-279 Repaired Area

When radiography of a repaired area is required, the length of the film used shall be at least equal to the length of the original location marker interval.

I-280 EVALUATION

I-285 Geometric and In-Motion Unsharpness Limitations

Neither the geometric nor in-motion unsharpness of the radiograph shall exceed the values specified in T-285.

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MANDATORY APPENDIX

APPENDIX II — REAL-TIME RADIOSCOPIC EXAMINATION

II-210 SCOPE

Real-time radioscopes provide immediate response imaging with the capability to follow motion of the inspected part. This includes radioscopes where the motion of the test object must be limited (commonly referred to as near real-time radioscopes).

Real-time radioscopes may be performed on materials including castings and weldments when the modified provisions to Article 2 as indicated herein are satisfied. SE-1255 shall be used in conjunction with this Appendix as indicated by specific references in appropriate paragraphs. SE-1416 provides additional information that may be used for radioscopic examination of welds.

II-220 GENERAL REQUIREMENTS

This radioscopic methodology may be used for the examination of ferrous or nonferrous materials and weldments.

II-221 Procedure Requirements

A written procedure is required and shall contain as a minimum the following (see SE-1255, 5.2):

- (a) material and thickness range
- (b) equipment qualifications
- (c) test object scan plan
- (d) radioscopic parameters
- (e) image processing parameters
- (f) image display parameters
- (g) image archiving

II-230 EQUIPMENT AND MATERIALS

II-231 Radioscopic Examination Record

The radioscopic examination data shall be recorded and stored on videotape, magnetic disk, or optical disk.

II-235 Calibration Block

The calibration block shall be made of the same material type and product form as the test object. The calibration block may be an actual test object or may be fabricated to simulate the test object with known discontinuities.

II-236 Calibrated Line Pair Test Pattern and Step Wedge

The line pair test pattern shall be used without an additional absorber to evaluate the system resolution. The step wedge shall be used to evaluate system contrast sensitivity.

The step wedge must be made of the same material as the test object with steps representing 100%, 99%, 98%, and 97% of both the thickest and the thinnest material sections to be inspected. Additional step thicknesses are permissible.

II-237 Equivalent Performance Level

A system which exhibits a spatial resolution of 3 line pairs per millimeter, a thin section contrast sensitivity of 3%, and a thick section contrast sensitivity of 2% has an equivalent performance level of 3% — 2% — 3 lp/mm.

II-260 CALIBRATION

System calibration shall be performed in the static mode by satisfying the line pair test pattern resolution, step wedge contrast sensitivity, and calibration block discontinuity detection necessary to meet the IQI requirements of T-276.

II-263 System Performance Measurement

Real-time radioscopic system performance parameters shall be determined initially and monitored regularly with the system in operation to assure consistent results.

The system performance shall be monitored at sufficiently scheduled intervals to minimize the probability of time-dependent performance variations. System performance tests require the use of the calibration block, line pair test pattern, and the step wedge.

System performance measurement techniques shall be standardized so that they may be readily duplicated at the specified intervals.

II-264 Measurement With a Calibration Block

The calibration block shall also be placed in the same position as the actual object and manipulated through the same range and speed of motions as will be used for the actual object to demonstrate the system's response in the dynamic mode.

II-270 EXAMINATION

II-278 System Configuration

The radioscopic examination system shall, as a minimum, include the following:

- (a) radiation source
- (b) manipulation system
- (c) detection system
- (d) information processing system
- (e) image display system
- (f) record archiving system

II-280 EVALUATION

II-286 Factors Affecting System Performance

The radioscopic examination system performance quality is determined by the combined performance of the components specified in II-278. (See SE-1255, 6.1.)

When using wire IQIs, the radioscopic examination system may exhibit asymmetrical sensitivity, therefore, the wire diameter axis shall be oriented along the axis of the least sensitivity of the system.

II-290 DOCUMENTATION

II-291 Radioscopic Technique Information

To aid in proper interpretation of the radioscopic examination data, details of the technique used shall accompany the data. As a minimum, the information shall include the items specified in T-291 when applicable, II-221, and the following:

- (a) operator identification
- (b) system performance test data

II-292 Evaluation by Manufacturer

Prior to being presented to the Inspector for acceptance, the examination data shall be interpreted by the Manufacturer as complying with the referencing Code Section. The Manufacturer shall record the interpretation and disposition of each weldment examined on a radiographic interpretation review form accompanying the radioscopic data.

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MANDATORY APPENDIX

APPENDIX III — DIGITAL IMAGE ACQUISITION, DISPLAY, AND STORAGE FOR RADIOGRAPHY AND RADIOSCOPY

III-210 SCOPE

Digital image acquisition, display, and storage can be applied to radiography and radioscopy. Once the analog image is converted to digital format, the data can be displayed, processed, quantified, stored, retrieved, and converted back to the original analog format, for example, film or video presentation.

Digital imaging of all radiographic and radioscopy examination test results shall be performed in accordance with the modified provisions to Article 2 as indicated herein.

III-220 GENERAL REQUIREMENTS

III-221 Procedure Requirements

A written procedure is required and shall contain, as a minimum, the following system performance parameters:

- (a) image digitizing parameters — modulation transfer function (MTF), line pair resolution, contrast sensitivity, and dynamic range;
- (b) image display parameters — format, contrast, and magnification;
- (c) image processing parameters that are used;
- (d) storage — identification, data compression, and media (including precautions to be taken to avoid data loss);
- (e) analog output formats.

III-222 Original Image Artifacts

Any artifacts that are identified in the original image shall be noted or annotated on the digital image.

III-230 EQUIPMENT AND MATERIALS

III-231 Digital Image Examination Record

The digital image examination data shall be recorded and stored on video tape, magnetic disk, or optical disk.

III-234 Viewing Considerations

The digital image shall be judged by visual comparison to be equivalent to the image quality of the original image at the time of digitization.

III-236 Calibrated Optical Line Pair Test Pattern and Optical Density Step Wedge

An optical line pair test pattern operating between 0.1 and 4.0 optical density shall be used to evaluate the modulation transfer function (MTF) of the system. The optical density step wedge shall be used to evaluate system contrast sensitivity.

III-250 IMAGE ACQUISITION AND STORAGE

III-255 Area of Interest

Any portion of the image data may be digitized and stored provided the information that is digitized and stored includes the area of interest as defined by the referencing Code Section.

III-258 System Configuration

The system shall, as a minimum, include the following:

- (a) digitizing system
- (b) display system
- (c) image processing system
- (d) image storage system

III-260 CALIBRATION

The system shall be calibrated for modulation transfer function (MTF), dynamic range, and contrast sensitivity.

III-263 System Performance Measurement

System performance parameters (as noted in III-221) shall be determined initially and monitored regularly with the system in operation to assure consistent results. The system performance shall be monitored at the beginning and end of each shift to minimize the probability of time-dependent performance variations.

III-280 EVALUATION**III-286 Factors Affecting System Performance**

The quality of system performance is determined by the combined performance of the components specified in III-258.

III-287 System-Induced Artifacts

The digital images shall be free of system-induced artifacts in the area of interest that could mask or be

confused with the image of any discontinuity in the original analog image.

III-290 DOCUMENTATION**III-291 Digital Imaging Technique Information**

To aid in proper interpretation of the digital examination data, details of the technique used shall accompany the data. As a minimum, the information shall include items specified in T-291 and II-221 when applicable, III-221, III-222, and the following:

- (a) operator identification
- (b) system performance test data

III-292 Evaluation by Manufacturer

Prior to being presented to the Inspector for acceptance, the digital examination data from a radiographic or radioscopy image shall have been interpreted by the Manufacturer as complying with the referencing Code Section.

The digital examination data from a radiograph that has previously been accepted by the Inspector is not required to be submitted to the Inspector for acceptance.

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MANDATORY APPENDIX

APPENDIX IV — INTERPRETATION, EVALUATION, AND DISPOSITION OF RADIOGRAPHIC AND RADIOSCOPIC EXAMINATION TEST RESULTS PRODUCED BY THE DIGITAL IMAGE ACQUISITION AND DISPLAY PROCESS

IV-210 SCOPE

The digital image examination test results produced in accordance with Article 2, Mandatory Appendix II, and Article 2, Mandatory Appendix III, may be interpreted and evaluated for final disposition in accordance with the additional provisions to Article 2 as indicated herein.

The digital information is obtained in series with radiography and in parallel with radioscopy. This data collection process also provides for interpretation, evaluation, and disposition of the examination test results.

IV-220 GENERAL REQUIREMENTS

The digital image shall be interpreted while displayed on a cathode ray tube (soft display). The interpretation may include density and contrast adjustment, quantification, and pixel measurement, including digital or optical density values and linear or area measurement.

The interpretation of a digitized image is dependent upon the same subjective evaluation by a trained interpreter as the interpretation of a radiographic or radioscopy image. Some of the significant parameters considered during interpretation include: area of interest, image quality, IQI image, magnification, density, contrast, discontinuity shape (rounded, linear, irregular), and artifact identification.

The digital image interpretation of the radiographic and radioscopy examination test results shall be performed in accordance with the modified provisions to Article 2 as indicated herein.

After the interpretation has been completed, the interpretation data and the digital image, which shall include

the unprocessed original full image and the digitally processed image, shall be recorded and stored on video tape, magnetic tape, or optical disk.

IV-221 Procedure Requirements

A written procedure is required and shall contain, as a minimum, the following system performance parameters:

(a) image digitizing parameters — modulation transfer function (MTF), line pair resolution, contrast sensitivity, dynamic range, and pixel size;

(b) image display parameters — monitor size including display pixel size, luminosity, format, contrast, and magnification;

(c) signal processing parameters — including density shift, contrast stretch, log transform, and any other techniques that do not mathematically alter the original digital data, e.g., linear and area measurement, pixel sizing, and value determination;

(d) storage — identification, data compression, and media (including precautions to be taken to avoid data loss). The non-erasable optical media should be used for archival applications. This is frequently called the WORM (Write Once Read Many) technology. When storage is accomplished on magnetic or erasable optical media, then procedures must be included that show trackable safeguards to prevent data tampering and guarantee data integrity.

IV-222 Original Image Artifacts

Any artifacts that are identified shall be noted or annotated on the digital image.

IV-230 EQUIPMENT AND MATERIALS

IV-231 Digital Image Examination Record

The digital image examination data shall be recorded and stored on video tape, magnetic disk, or optical disk.

IV-234 Viewing Considerations

The digital image shall be evaluated using appropriate monitor luminosity, display techniques, and room lighting to insure proper visualization of detail.

IV-236 Calibrated Optical Line Pair Test Pattern and Optical Density Step Wedge

An optical line pair test pattern operating between 0.1 and 4.0 optical density shall be used to evaluate the modulation transfer function (MTF) of the system. High spatial resolution with 14 line-pairs per millimeter (lp/mm) translates to a pixel size of 0.0014 in. (0.035 mm). Lesser spatial resolution with 2 lp/mm can be accomplished with a pixel size of 0.012 in. (0.3 mm). The optical density step wedge shall be used to evaluate system contrast sensitivity. Alternatively, a contrast sensitivity gage (step wedge block) in accordance with SE-1647 may be used.

IV-250 IMAGE ACQUISITION, STORAGE, AND INTERPRETATION**IV-255 Area of Interest**

The evaluation of the digital image shall include all areas of the image defined as the area of interest by the referencing Code Section.

IV-258 System Configuration

The system shall, as a minimum, include:

- (a) digital image acquisition system
- (b) display system
- (c) image processing system
- (d) image storage system

IV-260 CALIBRATION

The system shall be calibrated for modulation transfer function (MTF), dynamic range, and contrast sensitivity. The electrical performance of the hardware and the quality of the digital image shall be measured and recorded.

IV-263 System Performance Measurement

System performance parameters (as noted in IV-221) shall be determined initially and monitored regularly with the system in operation to assure consistent results. The system performance shall be monitored at the beginning and end of each shift to minimize the probability of time-dependent performance variations.

IV-280 EVALUATION**IV-286 Factors Affecting System Performance**

The quality of system performance is determined by the combined performance of the components specified in IV-258.

IV-287 System-Induced Artifacts

The digital images shall be free of system-induced artifacts in the area of interest that could mask or be confused with the image of any discontinuity.

IV-290 DOCUMENTATION**IV-291 Digital Imaging Technique Information**

To aid in proper interpretation of the digital examination data, details of the technique used shall accompany the data. As a minimum, the information shall include items specified in T-291 and II-221 when applicable, III-221, III-222, IV-221, IV-222, and the following:

- (a) operator identification
- (b) system performance test data
- (c) calibration test data

IV-292 Evaluation by Manufacturer

Prior to being presented to the Inspector for acceptance, the digital examination data from a radiographic or radioscopy image shall have been interpreted by the Manufacturer as complying with the referencing Code Section.

The digitized examination data that has previously been accepted by the Inspector is not required to be submitted to the Inspector for acceptance.

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MANDATORY APPENDIX

APPENDIX V — GLOSSARY OF TERMS FOR RADIOGRAPHIC EXAMINATION

V-210 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms relating to radiographic examination.

V-220 GENERAL REQUIREMENTS

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 Section 7 provides the definitions of terms listed in V-230(a).

(c) For general terms, such as *Indication*, *Flaw*, *Discontinuity*, *Evaluation*, etc., refer to Article 1, Mandatory Appendix I.

(d) Paragraph V-230(b) provides a list of terms and definitions that are Code specific. Paragraph V-230(c) provides a list of terms and definitions that are specific to Section V, Article 2, Appendix VI.

V-230 REQUIREMENTS

(a) The following SE-1316 terms are used in conjunction with this Article: *composite viewing*, *contrast sensitivity*, *contrast stretch*, *densitometer*, *density* (film), *digital image acquisition system*, *erasable optical medium*, *focal spot*, *intensifying screen*, *IQI sensitivity*, *line pair test pattern*, *location marker*, *luminosity*, *magnetic storage medium*, *optical density*, *pixel*, *pixel size*, *screen*, *source*, *step wedge*, *system-induced artifacts*, *transmission densitometer*, and *transmitted film density*.

(b) The following Code terms are used in conjunction with this Article.

annotate — to provide an explanatory note on the digital image

calibrated line pair test pattern — see *optical line pair test pattern*

calibrated step wedge film — a radiograph with discrete density steps, which is traceable to a national standard

cathode ray tube (soft display) — a device that produces an image by exciting a fluorescent substance with a magnetically guided beam

data compression — a reduction in the size of a digital data set to a smaller data set

density shift — a function that raises or lowers all density/greyscale values equally such that contrast is maintained within the data set

designated wire — the specific wire that must be discernible in the radiographic image of a wire-type image quality indicator

diaphragm — an aperture (opening) in a radiation opaque material that limits the usable beam size of a radiation source

digital — of, or relating to, data in the form of numerical digits (e.g., binary)

digitizing — the act of converting an analog measurement of a quantity to a digital value

display pixel size — the length and width dimensions of the smallest element of a displayed image

display system — a system that can display an array of pixels on a screen (CRT)

dynamic range — the range of operation of a device between its upper and lower limit; this range can be given as a ratio (e.g., 100:1) of the maximum signal level capability to its noise level, the number of measurable steps between the upper and lower limits, the number of bits needed to record this number of measurable steps, or the maximum and minimum measurable values

equivalent IQI sensitivity — that thickness of hole-type IQI, expressed as a percentage of the part thickness, in which 2T hole would be visible under the same radiographic conditions

essential hole — the specific hole that must be discernible in the radiographic image of a hole-type IQI

image processing system — a system that uses mathematical algorithms to manipulate digital image data

image quality indicator

hole type — a rectangular plaque, made of material radiographically similar to that of the object being radiographed, with small diameter holes (1T, 2T, and 4T) used to check the image quality of the radiograph

wire type — a set of small diameter wires, made of material radiographically similar to that of the object being radiographed, used to check the image quality of the radiograph

image storage system — a system that can store digital image data for future use

IQI — image quality indicator

line pair resolution — the number of line pairs per unit distance that are detectable in an image

log transform — a function that applies a logarithmic mapping to all density/greyscale values in an image; this operation is often performed when the resulting distribution is normal, or if the resulting relationship with another variable is linear

modulation transfer function (MTF) — a measure of spatial resolution as a function of contrast; a plot of these variables (spatial resolution and contrast) yields a curve representing the frequency response of the system

national standard step tablet — an x-ray film with discrete density steps produced and certified by a nationally recognized standardizing body

nonerasable optical media (optical disk) — a storage media that prevents the erasure or alteration of digital data after it is stored

optical density step wedge — a radiographic image of a mechanical step wedge with precise thickness increments and may be used to correlate optical film density to the thickness of material, also known as a step tablet

penetrameter — no longer used in Article 2; see *image quality indicator*

quantification — the act of determining or expressing a quantity (i.e., giving a numerical value to a measurement of something)

radiographic examination — a nondestructive method for detecting discontinuities in materials and components using penetrating radiation to produce an image on a recording medium

sensitivity — the smallest discernible detail and/or contrast change (e.g., IQI hole or wire) in a radiographic image

shim — a material, radiographically similar to the object being radiographed, that is placed between a hole-type IQI and the object in order to reduce the radiographic density through the image of the hole-type IQI

source side — that surface of the area of interest being radiographed for evaluation nearest the source of radiation

WORM (write once read many) — a term relating to a type of digital storage media where the data can be stored only once but accessed (nondestructively) many times

(c) The following Code terms are used in conjunction with Article 2, Appendix VI:

contrast sensitivity — the size of the smallest detectable change in optical density

dynamic range — the extent of measurable optical density obtained in a single scan

image — the digital representation of a target on the reference film used to evaluate both the digitization and display aspects of a film digitization system

reference film — a single industrial radiographic film that encompasses the targets necessary for the evaluation and quantification of the performance characteristics of a film digitization system

spatial linearity — the accuracy to which a digitization system reproduces the physical dimensions of information on the original film [both in the horizontal (along a single scan line) and vertical (from one scan line to another) directions]

spatial resolution — the size of the smallest detectable element of the digitized image

step wedge calibration film — a processed film with discrete density steps that have been verified by comparison with a national standard step tablet

step wedge comparison film — a processed film with discrete density steps that have been verified by use of a calibrated densitometer, which is used to determine if production radiographs meet density limits

target — a physical pattern on a reference film used to evaluate the performance of a film digitization system

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APPENDIX VI — DIGITAL IMAGE ACQUISITION, DISPLAY, INTERPRETATION, AND STORAGE OF RADIOGRAPHS FOR NUCLEAR APPLICATIONS

VI-210 SCOPE

Digital imaging process and technology provide the ability to digitize and store the detailed information contained in the radiograph (analog image), thus eliminating the need to maintain and store radiographs for permanent record.

VI-220 GENERAL REQUIREMENTS

VI-221 Supplemental Requirements

VI-221.1 Additional Information. Article 2, Mandatory Appendices III and IV, contain additional information that shall be used to supplement the requirements of this Appendix. These supplemental requirements shall be documented in the written procedure required by this Appendix.

VI-221.2 Reference Film. Supplement A contains requirements for the manufacture of the reference film.

VI-222 Written Procedure

A written procedure is required. The written procedure shall be the responsibility of the owner of the radiographs and shall be demonstrated to the satisfaction of the Authorized Nuclear Inspector (ANI). When other enforcement or regulatory agencies are involved, the agency approval is required by formal agreement. The written procedure shall include, as a minimum, the following essential variables:

VI-222.1 Digitizing System Description

- (a) manufacturer and model no. of digitizing system;
- (b) physical size of the usable area of the image monitor;
- (c) film size capacity of the scanning device;

- (d) spot size(s) of the film scanning system;
- (e) image display pixel size as defined by the vertical/horizontal resolution limits of the monitor;
- (f) luminance of the video display; and
- (g) data storage medium.

VI-222.2 Digitizing Technique

- (a) digitizer spot size (in microns) to be used (see VI-232);
- (b) loss-less data compression technique, if used;
- (c) method of image capture verification;
- (d) image processing operations;
- (e) time period for system verification (see VI-264);
- (f) spatial resolution used (see VI-241);
- (g) contrast sensitivity (density range obtained) (see VI-242);
- (h) dynamic range used (see VI-243); and
- (i) spatial linearity of the system (see VI-244).

VI-223 Personnel Requirements

Personnel shall be qualified as follows:

(a) *Level II and Level III Personnel.* Level II and Level III personnel shall be qualified in the radiographic method as required by Article 1. In addition, the employer's written practice shall describe the specific training and practical experience of Level II and Level III personnel involved in the application of the digital imaging process and the interpretation of results and acceptance of system performance. Training and experience shall be documented in the individual's certification records.

(b) As a minimum, Level II and III individuals shall have 40 hours of training and 1 month of practical experience in the digital imaging process technique.

(c) *Other Personnel.* Personnel with limited qualifications performing operations other than those required for the Level II or Level III shall be qualified in accordance with Article 1. Each individual shall have specified training and practical experience in the operations to be performed.

VI-230 EQUIPMENT AND MATERIALS**VI-231 System Features**

The following features shall be common to all digital image processing systems:

- (a) noninterlaced image display format;
- (b) *WORM* — write-once/read-many data storage; and
- (c) fully reversible (loss-less) data compression (if data compression is used).

VI-232 System Spot Size

The spot size of the digitizing system shall be:

- (a) 70 microns, or smaller for radiographs made with energies up to 1 MeV; or
- (b) 100 microns or smaller for radiographs made with energies over 1 MeV.

VI-240 SYSTEM PERFORMANCE REQUIREMENTS

System performance shall be determined using the digitized representation of the reference targets (images). No adjustment shall be made to the digitizing system which may affect system performance after recording the reference targets.

VI-241 Spatial Resolution

Spatial resolution shall be determined as described in VI-251. The system shall be capable of resolving a pattern of 7 line pairs/millimeter (lp/mm) for systems digitizing with a spot size of 70 microns or less, or 5 line pairs/millimeter for spot sizes greater than 70 microns.

VI-242 Contrast Sensitivity

Contrast sensitivity shall be determined as described in VI-252. The system shall have a minimum contrast sensitivity of 0.02 optical density.

VI-243 Dynamic Range

Dynamic range shall be determined as described in VI-253. The system shall have a minimum dynamic range of 3.5 optical density.

VI-244 Spatial Linearity

Spatial linearity shall be determined as described in VI-254. The system shall return measured dimensions with 3% of the actual dimensions on the reference film.

VI-250 TECHNIQUE

The reference film described in Supplement A and Fig. VI-A-1 shall be used to determine the performance of the digitization system. The system settings shall be adjusted to optimize the display representation of the reference targets (images). The reference film and all subsequent radiographs shall be scanned by the digitization system using these optimized settings.

VI-251 Spatial Resolution Evaluation

At least two of the converging line pair images (0 deg., 45 deg., and 90 deg. line pairs) shall be selected near the opposite corners of the digitizing field and one image near the center of the digitized reference film. The spatial resolution in each position and for each orientation shall be recorded as the highest indicated spatial frequency (as determined by the reference lines provided) where all of the lighter lines are observed to be separated by the darker lines. The system resolution shall be reported as the poorest spatial resolution obtained from all of the resolution images evaluated.

VI-252 Contrast Sensitivity Evaluation

Using the contrast sensitivity images and the digitized stepped density scale images to evaluate the detectability of each density step (the observed density changes shall be indicative of the system's capability to discern 0.02 density differences), the detectability of each density step and the difference in density between steps shall be evaluated.

VI-253 Dynamic Range Evaluation

The dynamic range of the digitization system shall be determined by finding the last visible density step at both ends of the density strip. The dynamic range shall be measured to the nearest 0.50 optical density.

VI-254 Spatial Linearity Evaluation

The digitization system shall be set to read the inch scale on the reference film. The measurement tool shall then be used to measure the scale in a vertical direction and horizontal direction. The actual dimension is divided

by the measured dimension to find the percentage of error in the horizontal and vertical directions.

VI-260 DEMONSTRATION OF SYSTEM PERFORMANCE

VI-261 Procedure Demonstration

The written procedure described in VI-222 shall be demonstrated to the ANI and, if requested, the regulatory agency, as having the ability to acquire, display, and reproduce the analog images from radiographs. Evidence of the demonstration shall be recorded as required by VI-291.

VI-262 Processed Targets

The digitizing process and equipment shall acquire and display the targets described in Supplement A. The digitally processed targets of the reference film shall be used to verify the system performance.

VI-263 Changes in Essential Variables

Any change in the essential variables identified in VI-222 and used to produce the results in VI-250 shall be cause for reverification of the System Performance.

VI-264 Frequency of Verification

The System Performance shall be initially verified in accordance with VI-262 at the beginning of each digitizing shift. Reverification in accordance with VI-262 shall take place at the end of each shift or at the end of 12 continuous hours, whichever is less, or at any time that malfunctioning is suspected.

VI-265 Changes in System Performance

Any evidence of change in the System Performance specified in VI-240 shall invalidate the digital images processed since the last successful verification and shall be cause for reverification.

VI-270 EXAMINATION

VI-271 System Performance Requirements

The digitizing system shall meet the requirements specified in VI-240 before digitizing archival radiographs.

VI-272 Artifacts

Radiographs shall be visually examined for foreign material and artifacts (e.g., scratches or water spots) in the area of interest. Foreign material not removed and artifacts observed shall be documented.

VI-273 Calibration

The calibration for a specific set of parameters (i.e., film size, density range, and spatial resolution) shall be conducted by following VI-240 and Supplement A. The results shall be documented.

VI-280 EVALUATION

VI-281 Process Evaluation

The Level II or Level III Examiner described in VI-223(a) shall be responsible for determining that the digital imaging process is capable of reproducing the original analog image. This digital image shall then be transferred to the write-once-read-many (WORM) optical disc.

VI-282 Interpretation

When interpretation of the radiograph is used for acceptance, the requirements of Article 2, Mandatory Appendix IV and the Referencing Code Section shall apply. If analog radiographs must be viewed in composite for acceptance, then both radiographs shall be digitized. The digital image of the analog radiographs shall be interpreted singularly.

VI-283 Baseline

Digital images of previously accepted radiographs may be used as a baseline for subsequent in-service inspections.

VI-290 DOCUMENTATION

VI-291 Reporting Requirements

The following shall be documented in a final report:

- (a) spatial resolution (VI-241);
- (b) contrast sensitivity (VI-242);
- (c) frequency for system verification;
- (d) dynamic range (VI-243);
- (e) Traceability technique from original component to radiograph to displayed digital image, including original radiographic report(s). (The original radio-

graphic reader sheet may be digitized to fulfill this requirement);

- (f) condition of original radiographs (VI-281);
- (g) procedure demonstration (VI-261);
- (h) spatial linearity (VI-244);
- (i) system performance parameters (VI-241); and
- (j) personnel performing the digital imaging process (VI-223).

VI-292 Archiving

When the final report and digitized information are used to replace the analog radiograph as the permanent record as required by the referencing Code Section, all information pertaining to the original radiography shall be documented in the final report and processed as part of the digital record. A duplicate copy of the WORM storage media is required if the radiographs are to be destroyed.

ARTICLE 2 MANDATORY APPENDIX VI — SUPPLEMENT A

VI-A-210 SCOPE

The reference film described in this supplement provides a set of targets suitable for evaluating and quantifying the performance characteristics of a radiographic digitizing system. The reference film is suitable for evaluating both the radiographic film digitization process and the electronic image reconstruction process.

The reference film shall be used to conduct performance demonstrations and evaluations of the digitizing system to verify the operating characteristics before radiographs are digitized. The reference film provides for the evaluation of spatial resolution, contrast sensitivity, dynamic range, and spatial linearity.

01 VI-A-220 GENERAL

VI-A-221 Reference Film

The reference film shall be specified in VI-A-230 and VI-A-240.

01 VI-A-230 EQUIPMENT AND MATERIALS

VI-A-231 Reference Targets

The illustration of the reference film and its targets is as shown in Fig. VI-A-1.

VI-A-232 Spatial Resolution Targets

The reference film shall contain spatial resolution targets as follows:

VI-A-232.1 Converging Line Pair Targets. Converging line pairs shall consist of 3 identical groups of no less than 6 converging line pairs (6 light lines and 6 dark lines). The targets shall have a maximum resolution of no less than 20 line pairs per millimeter (lp/mm) and a minimum resolution of no greater than 1 lp/mm. The 3 line pair groups shall be oriented in the vertical, horizontal, and the last group shall be 45 deg. from the previous two groups. The maximum resolution shall be oriented toward the corners of the film. Reference marks shall be provided to indicate spatial resolution at levels of no less than 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, and 20 lp/mm. The spatial resolution targets shall be located in each corner of the needed film sizes.

VI-A-232.2 Parallel Line Pair Targets. Parallel line pairs shall consist of parallel line pairs in at least the vertical direction on the reference film. It shall have a maximum resolution of at least 20 lp/mm and a minimum resolution of no less than 0.5 lp/mm. It shall have distinct resolutions of 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, and 20 lp/mm and have the corresponding reference marks. It shall be located near the middle of the reference film.

VI-A-233 Contrast Sensitivity Targets

Contrast sensitivity targets shall consist of approximately 0.4 in. by 0.4 in. (10 mm by 10 mm) blocks centered in 1.6 in. by 1.6 in. (40 mm by 40 mm) blocks of a slightly lower density. Two series of these step blocks shall be used with an optical density of approximately 2.0 on a background of approximately 1.95, an optical density change of 0.05. The second block series will have an optical density of approximately 3.5 on a background of approximately 3.4, an optical density change of 0.10. The relative density change is more important than the absolute density. These images shall be located near the edges and the center of the film so as to test the contrast sensitivity throughout the scan path.

VI-A-234 Dynamic Range Targets

Stepped density targets shall consist of a series of 0.4 in. by 0.4 in. (10 mm by 10 mm) steps aligned in a row with densities ranging from 0.5 to 4.5 with no greater than 0.5 optical density steps. At four places

on the density strip (at approximately 1.0, 2.0, 3.0, and 4.0 optical densities), there shall be optical density changes of 0.02 which shall also be used to test the contrast sensitivity. These stepped density targets shall be located near the edges of the film and near the center so as to test the dynamic range throughout the scan path.

01 VI-A-235 Spatial Linearity Targets

Measurement scale targets shall be located in the horizontal and vertical dimensions. The measurement scale targets shall be in English and/or metric divisions.

01 VI-A-240 MISCELLANEOUS REQUIREMENTS

Manufacturing specifications shall be minimum requirements necessary for producing the reference film. The reference film shall have a unique identification which appears as an image when digitized.

VI-A-241 Material

The reference film shall be a fine grain, industrial type film. The film used will be of high quality so the required specifications in VI-A-230 are met.

VI-A-242 Film Size

The film size shall be sufficient to accommodate the largest area of interest to be digitized.

VI-A-243 Spatial Resolution

The spatial resolution shall be a minimum of 20 lp/mm.

VI-A-244 Density

01

The relative densities stated in VI-A-233 and VI-A-234 shall be within ± 0.005 optical density.

(a) The tolerance for the optical density changes stated in VI-A-233 and VI-A-234 shall be ± 0.005 .

(b) The measured densities shall be within ± 0.15 of the values stated in VI-A-233 and VI-A-234. The actual densities shall be recorded and furnished with the reference film.

(c) Density requirements shall be in accordance with ANSI IT-2.19.

(d) The background density, where there are no images located, shall have a 3.0 optical density ± 0.5 .

VI-A-245 Linearity

The measurement scale targets shall be accurately electronically produced to ± 0.05 in. (± 1.3 mm).

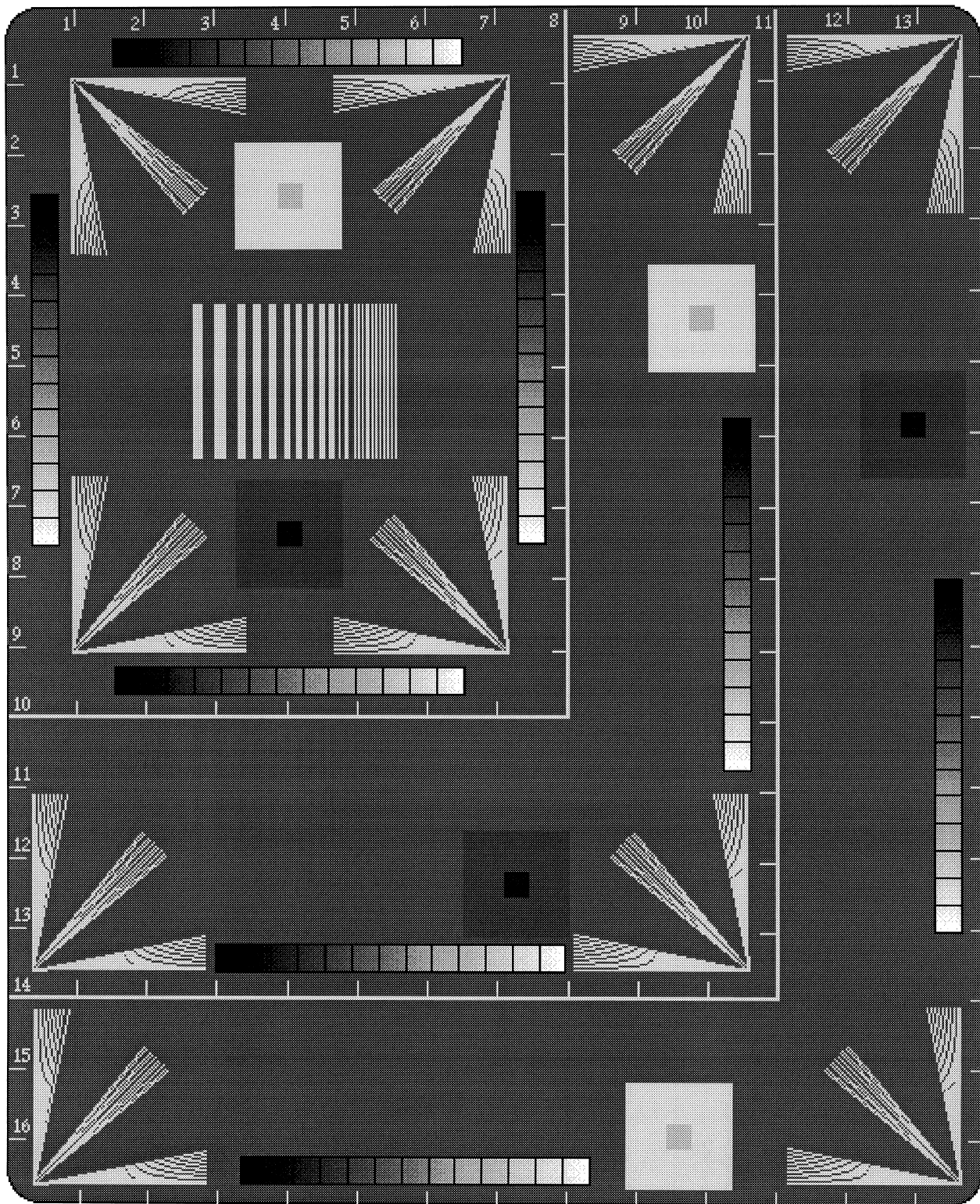


FIG. VI-A-1 REFERENCE FILM

ARTICLE 2

MANDATORY APPENDIX

APPENDIX VII — RADIOGRAPHIC EXAMINATION OF METALLIC CASTINGS

VII-210 SCOPE

Metallic castings, due to their inherent complex configurations, present examination conditions that are unique to this product form.

Radiographic examination may be performed on castings when the modified provisions to Article 2, as indicated herein, are satisfied.

VII-220 GENERAL REQUIREMENTS

VII-224 System of Identification

A system shall be used to produce permanent identification on the radiograph traceable to the contract, component, or part numbers, as appropriate. In addition, each film of a casting being radiographed shall be plainly and permanently identified with the name or symbol of the Material Manufacturer, Certificate Holder, or Subcontractor, job or heat number, date, and, if applicable, repairs (R1, R2, etc.). This identification system does not necessarily require that the information appear as radiographic images. In any case, this information shall not obscure the area of interest.

VII-270 EXAMINATION

VII-271 Radiographic Technique

VII-271.2 Double-Wall Viewing Technique. A double-wall viewing technique may be used for cylindrical castings $3\frac{1}{2}$ in. (89 mm) or less in O.D. or when the shape of a casting precludes single-wall viewing.

VII-276 IQI Selection

VII-276.3 Additional IQI Selection Requirements. The thickness on which the IQI is based is the single-wall thickness.

(a) *Casting Areas Prior to Finish Machining.* The IQI shall be based on a thickness that does not exceed the finished thickness by more than 20% or $\frac{1}{4}$ in. (6.4 mm), whichever is greater. In no case shall an IQI size be based on a thickness greater than the thickness being radiographed.

(b) *Casting Areas That Will Remain in the As-Cast Condition.* The IQI shall be based on the thickness being radiographed.

VII-280 EVALUATION

VII-282 Radiographic Density

VII-282.1 Density Limitations. The transmitted film density through the radiographic image of the body of the appropriate hole IQI or adjacent to the designated wire of a wire IQI and the area of interest shall be 1.5 minimum for single film viewing. For composite viewing of multiple film exposures, each film of the composite set shall have a minimum density of 1.0. The maximum density shall be 4.0 for either single or composite viewing. A tolerance of 0.05 in density is allowed for variations between densitometer readings.

VII-290 DOCUMENTATION

VII-293 Layout Details¹

To assure that all castings are radiographed consistently in the same manner, layout details shall be provided. As a minimum, the layout details shall include:

(a) sketches of the casting, in as many views as necessary, to show the approximate position of each location marker; and

(b) source angles if not perpendicular to the film.

¹ Sample layout and technique details are illustrated in SE-1030, Appendix (Nonmandatory Information) X1, Fig. X1.1.1, Radiographic Standard Shooting Sketch (RSS).

ARTICLE 2

NONMANDATORY APPENDIX

APPENDIX A — TECHNIQUE SKETCHES FOR PIPE OR TUBE WELDS

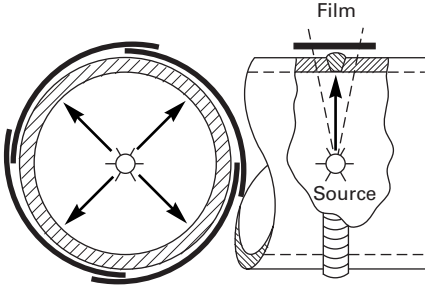
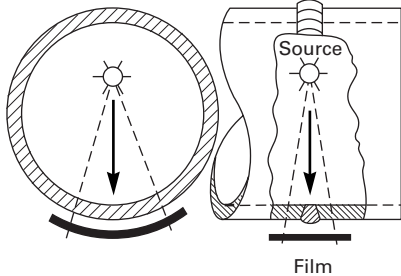
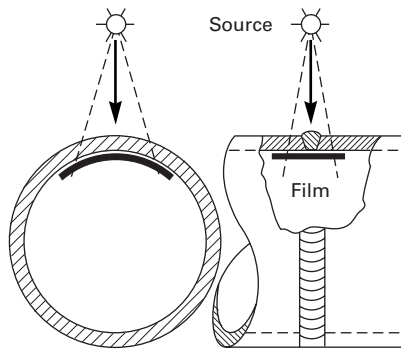
A-210 SCOPE

The sketches in the Appendix illustrate techniques used in the radiographic examination of pipe or tube welds.

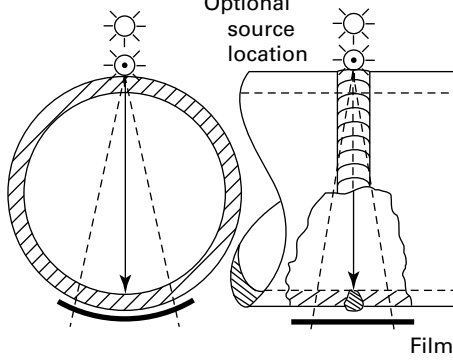
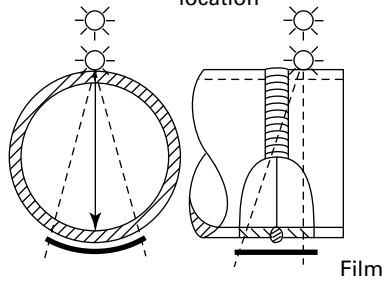
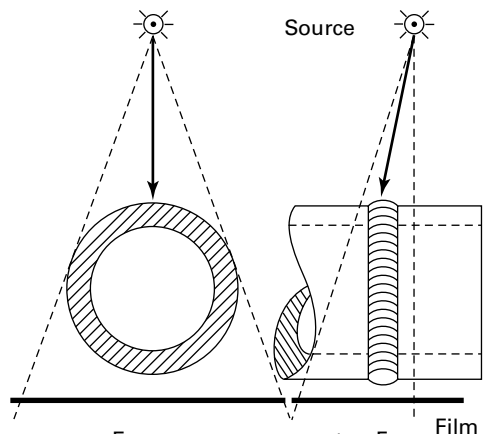
Other techniques may be used.

ARTICLE 2 — NONMANDATORY APPENDIX

SINGLE-WALL RADIOGRAPHIC TECHNIQUES

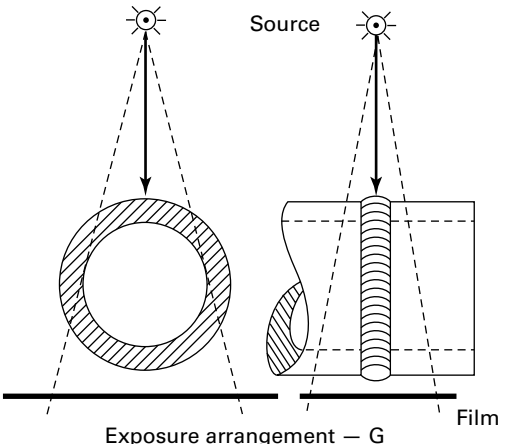
Pipe O.D.	Exposure Technique	Radiograph Viewing	Source-Weld-Film Arrangement		IQI		Location Marker Placement
			End View	Side View	Selection	Placement	
Any	Single-Wall T-271.1	Single-Wall	 Exposure Arrangement — A		T-276 and Table T-276	Source Side T-277.1(a)	Either Side T-275.3 T-275.1(c)
						Film Side T-277.1(b)	
Any	Single-Wall T-271.1	Single-Wall	 Exposure Arrangement — B		T-276 and Table T-276	Source Side T-277.1(a)	Film Side T-275.1 (b)(1)
						Film Side T-277.1(b)	
Any	Single-Wall T-271.1	Single-Wall	 Exposure Arrangement — C		T-276 and Table T-276	Source Side T-277.1(a)	Source Side T-275.1 (a)(3)
						Film Side T-277.1(b)	

DOUBLE-WALL RADIOGRAPHIC TECHNIQUES

Pipe O.D.	Exposure Technique	Radiograph Viewing	Source-Weld-Film Arrangement		IQI		Location Marker Placement
			End View	Side View	Selection	Placement	
Any	Double-Wall: T-271.2(a) at Least 3 Exposures 120 deg. to Each Other for Complete Coverage	Single-Wall	 Optional source location Film Exposure arrangement — D		T-276 and Table T-276	Source Side T-277.1(a) Film Side T-277.1(b)	Film Side T-275.1(b)(1)
Any	Double-Wall: T-271.2(a) at least 3 Exposures 120 deg. to Each Other for Complete Coverage	Single-Wall	 Optional source location Film Exposure arrangement — E		T-276 and Table T-276	Source Side T-277.1(a) Film Side T-277.1(b)	Film Side T-275.1(b)(1)
3½ in. (89 mm) or Less	Double-Wall T-271.2(b)(1) at Least 2 Exposures at 90 deg. to Each Other for Complete Coverage	Double-Wall (Ellipse): Read Offset Source Side and Film Side Images	 Source Film Exposure arrangement — F		T-276 and Table T-276	Source Side T-277.1(a)	Either Side T-275.2

(continued)

DOUBLE-WALL RADIOGRAPHIC TECHNIQUES (CONT'D)

Pipe O.D.	Exposure Technique	Radiograph Viewing	Source-Weld-Film Arrangement		IQI		Location Marker Placement
			End View	Side View	Selection	Placement	
3½ in. (89 mm) or Less	Double-Wall: T-271.2(b)(2) at Least 3 Exposures at 60 deg. or 120 deg. to Each Other for Complete Coverage	Double-Wall: Read Super-imposed Source Side and Film Side Images			T-276 and Table T-276	Source Side T-277.1(a)	Either Side T-275.2

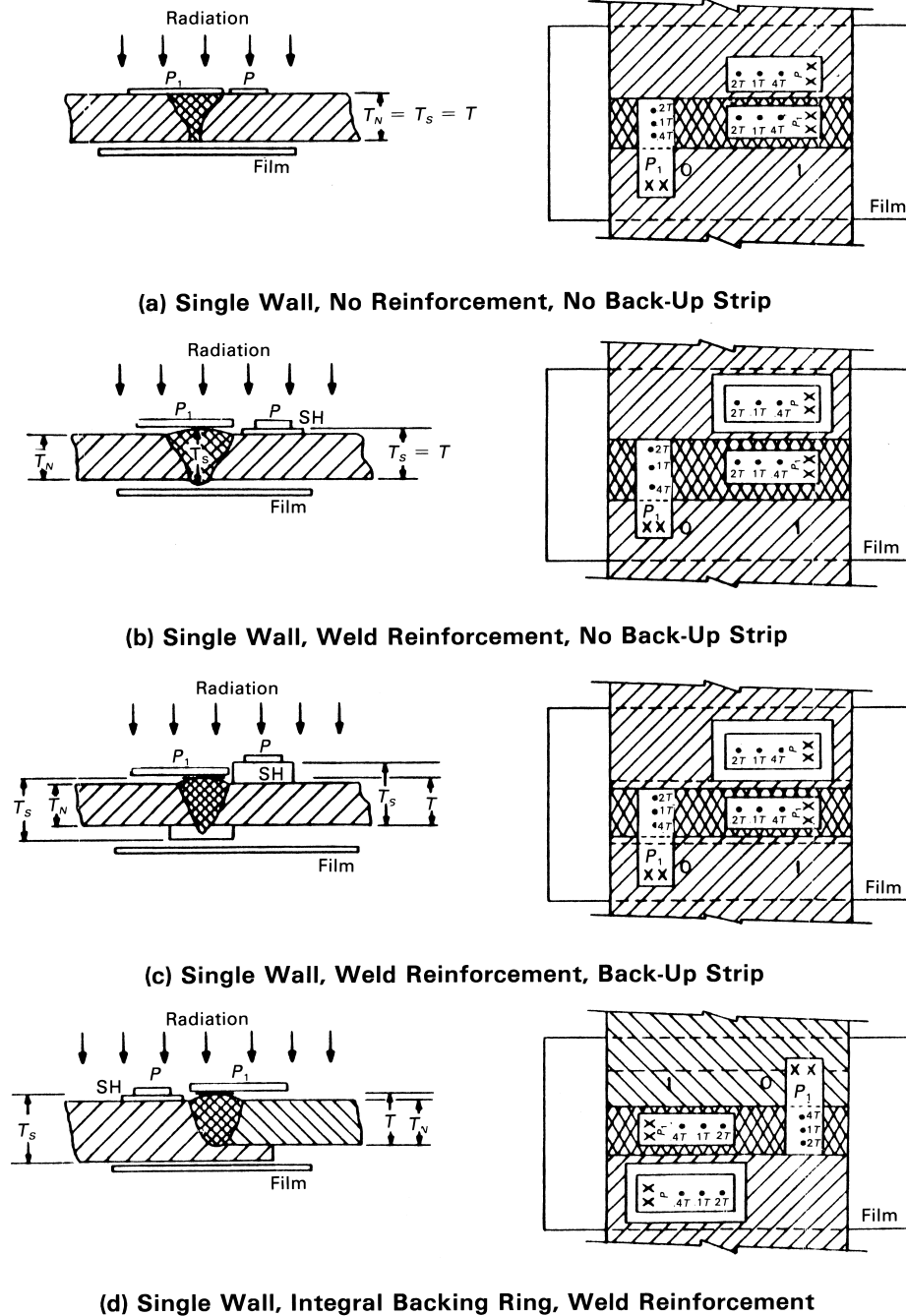
ARTICLE 2

NONMANDATORY APPENDIX

APPENDIX C — HOLE-TYPE IQI PLACEMENT SKETCHES FOR WELDS

C-210 SCOPE

The figures in this Appendix demonstrate typical IQI (hole type) placement for welds. These sketches are tutorial to demonstrate suggested locations of IQIs and are not intended to cover all configurations or applications of production radiography. Other IQI locations may be used provided they comply with the requirements of Article 2. Wire IQIs shall be placed in accordance with the requirements of Article 2.

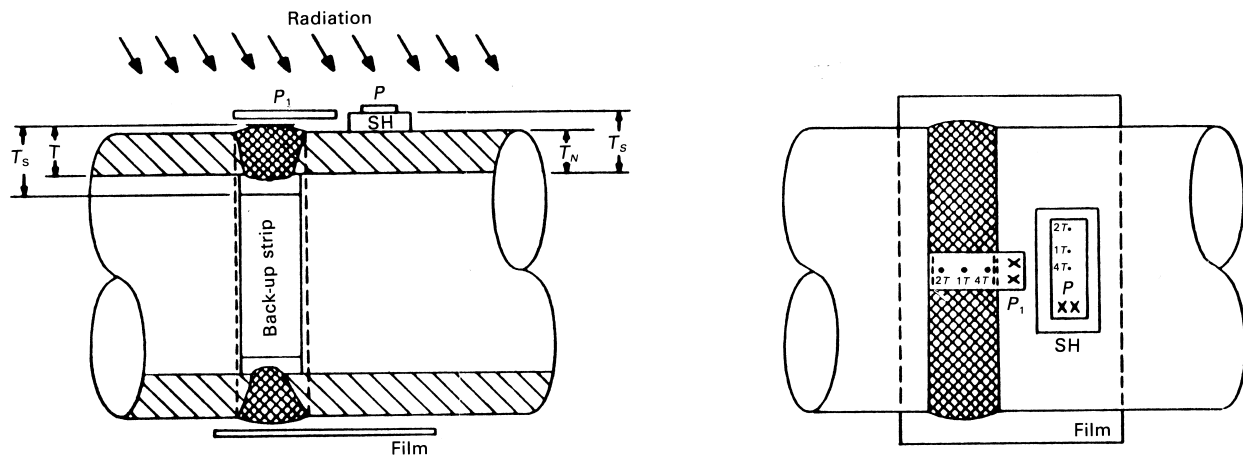
**GENERAL NOTE:**

P and P_1 are suggested placements of IQIs and are not intended to cover all geometric configurations or applications of production radiography.

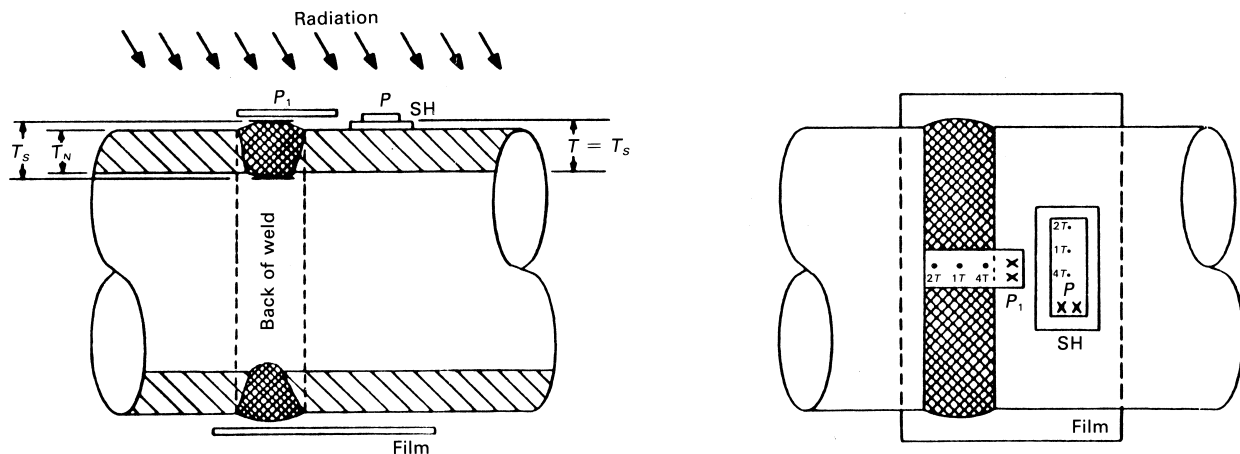
LEGEND:

P = IQI placement
 P_1 = alternate IQI placement
 SH = shim
 T = weld thickness upon which the IQI is based
 T_N = nominal wall thickness
 T_S = total thickness including backing strip and/or reinforcement when not removed

FIG. C-210-1 SIDE AND TOP VIEWS OF HOLE-TYPE IQI PLACEMENTS



(a) Double-Wall Technique, Double-Wall Viewing, With Weld Reinforcement and Back-Up Strip



(b) Double-Wall Technique, Double-Wall Viewing, With Weld Reinforcement and No Back-Up Strip

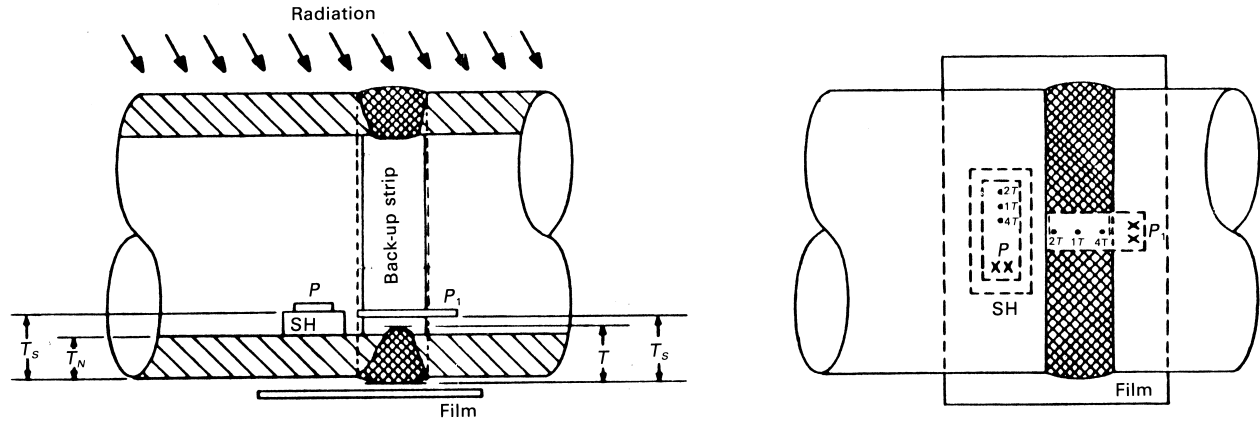
GENERAL NOTES:

- (a) P and P_1 are suggested placements of IQIs and are not intended to cover all geometric configurations or applications of production radiography.
- (b) IQI is based on the single-wall thickness plus reinforcement.

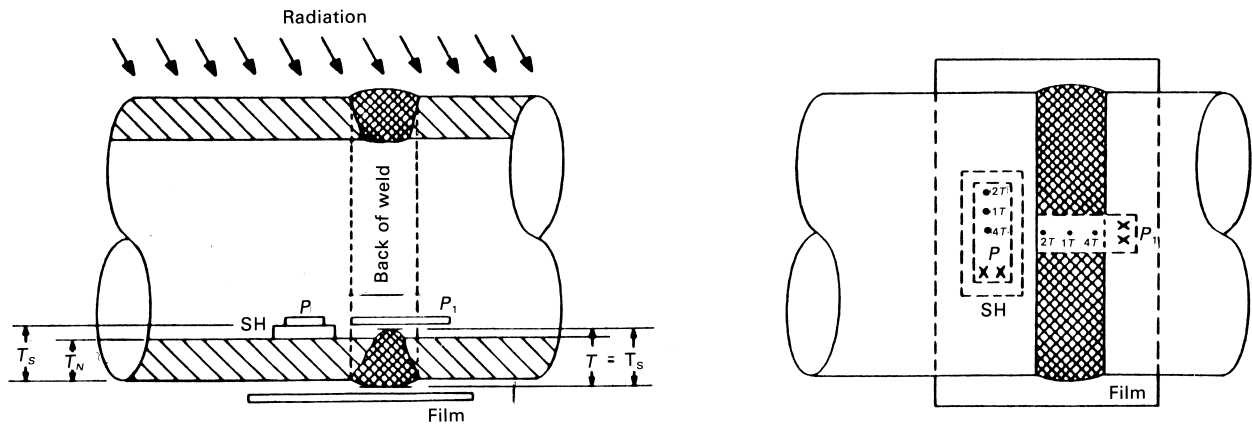
LEGEND:

- P = IQI placement
 P_1 = alternate IQI placement
 SH = shim
 T = weld thickness upon which the IQI is based
 T_N = nominal wall thickness
 T_S = total thickness including backing strip and/or reinforcement when not removed

FIG. C-210-2 SIDE AND TOP VIEWS OF HOLE-TYPE IQI PLACEMENTS



(a) Double-Wall Technique, Single-Wall Viewing, Back-Up Strip



(b) Double-Wall Technique, Single-Wall Viewing, Wall Reinforcement, No Back-Up Strip

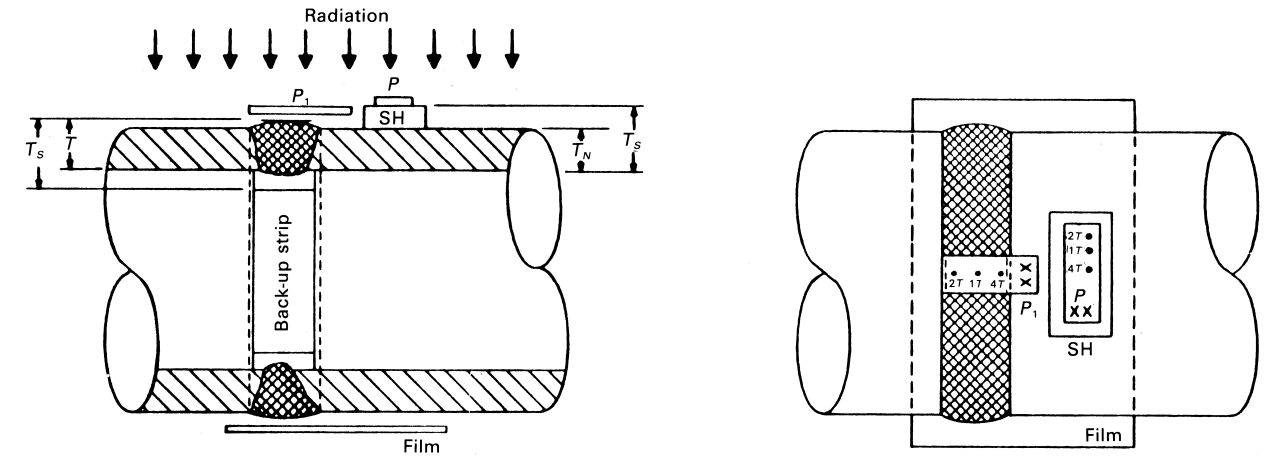
GENERAL NOTE:

P and P_1 are suggested placements of IQIs and are not intended to cover all geometric configurations or applications of production radiography.

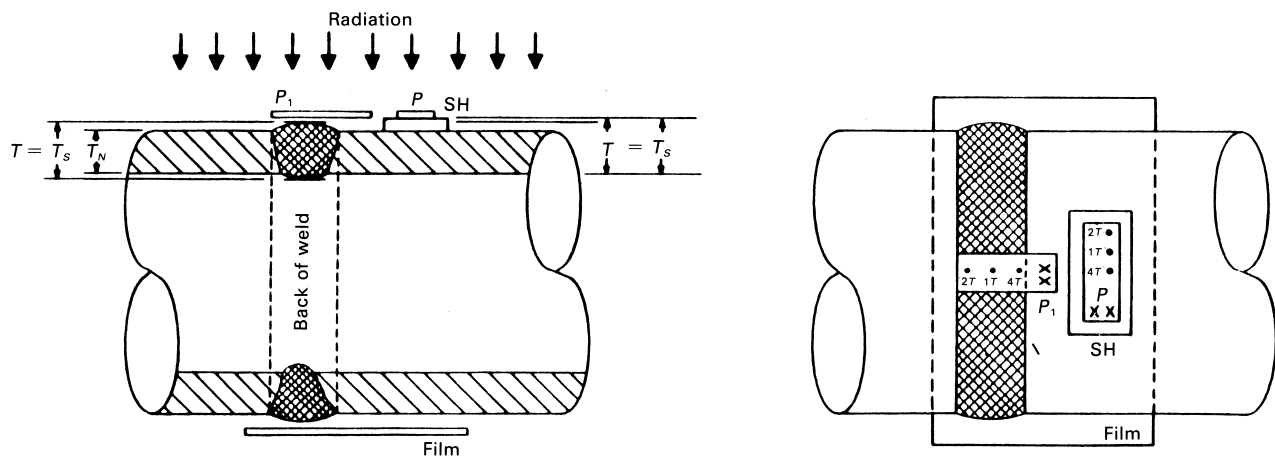
LEGEND:

P = IQI placement
 P_1 = alternate IQI placement
 SH = shim
 T = weld thickness upon which the IQI is based
 T_N = nominal wall thickness
 T_S = total thickness including backing strip and/or reinforcement when not removed

FIG. C-210-3 SIDE AND TOP VIEWS OF HOLE-TYPE IQI PLACEMENTS



(a) Double-Wall Technique, Double-Wall Viewing, With Weld Reinforcement and Back-Up Strip



(b) Double-Wall Technique, Double-Wall Viewing, With Weld Reinforcement and No Back-Up Strip

GENERAL NOTES:

- (a) P and P_1 are suggested placements of IQIs and are not intended to cover all geometric configurations or applications of production radiography.
- (b) IQI is based on the single-wall thickness plus reinforcement.

LEGEND:

- P = IQI placement
 P_1 = alternate IQI placement
 SH = shim
 T = weld thickness upon which the IQI is based
 T_N = nominal wall thickness
 T_S = total thickness including backing strip and/or reinforcement when not removed

FIG. C-210-4 SIDE AND TOP VIEWS OF HOLE-TYPE IQI PLACEMENTS

ARTICLE 2

NONMANDATORY APPENDIX

APPENDIX D — NUMBER OF IQIs (SPECIAL CASES)

D-210 SCOPE

The figures in this Appendix illustrate examples of the number and placement of IQIs that may be used in the special cases described in T-277.2(b). These figures are not intended to cover all configurations or applications of production radiography.

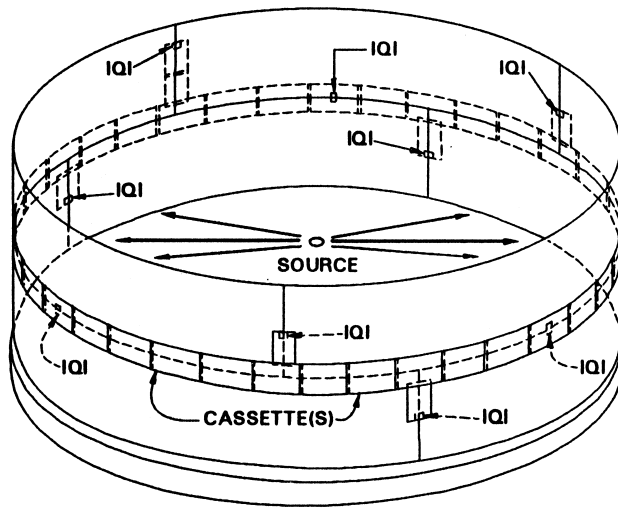


FIG. D-210-1 COMPLETE CIRCUMFERENCE
CYLINDRICAL COMPONENT
[T-277.2(b)(1)(a) & T-277.2(b)(3)]

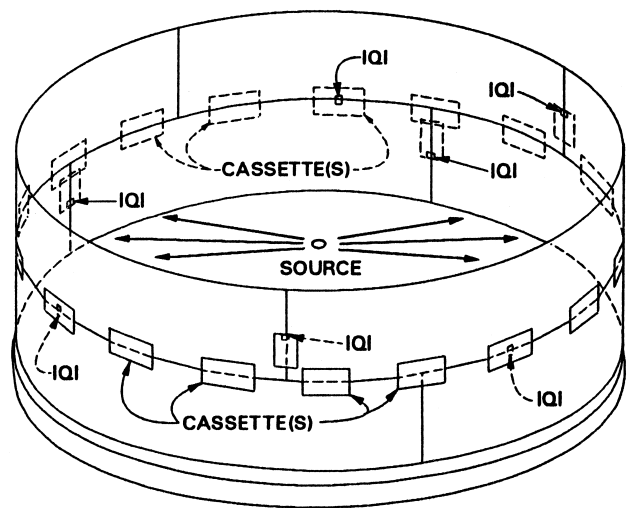


FIG. D-210-2 SECTION OF CIRCUMFERENCE
240 deg. OR MORE CYLINDRICAL COMPONENT
(EXAMPLE IS ALTERNATE INTERVALS)
[T-277.2(b)(1)(b) & T-277.2(b)(3)]

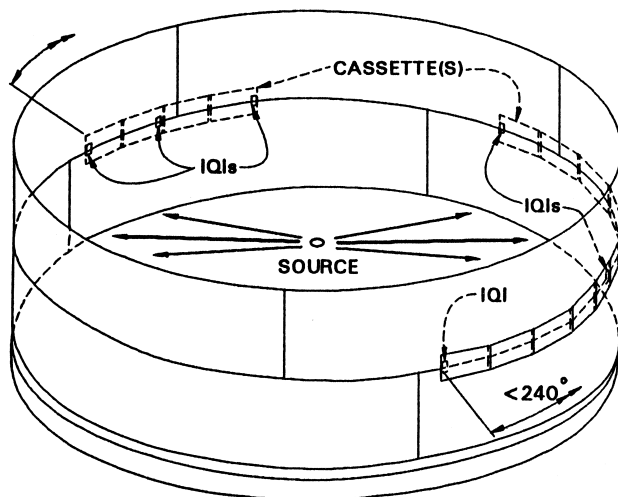


FIG. D-210-3 SECTION(S) OF CIRCUMFERENCE
LESS THAN 240 deg. CYLINDRICAL COMPONENT
[T-277.2(b)(2)(b)]

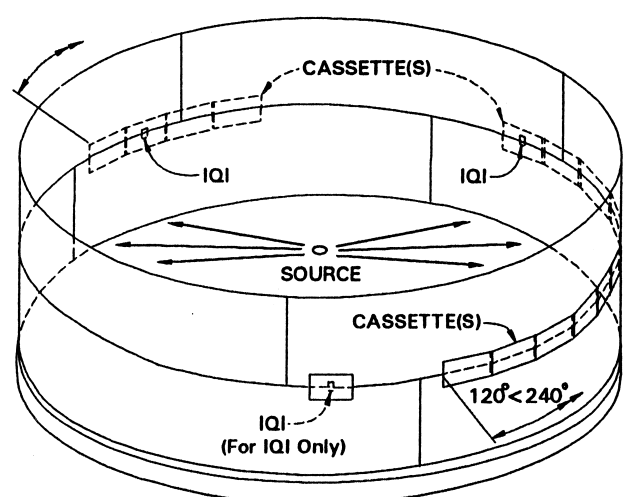


FIG. D-210-4 SECTION(S) OF CIRCUMFERENCE
EQUAL TO OR MORE THAN 120 deg. AND LESS
THAN 240 deg. CYLINDRICAL COMPONENT
[T-277.2(b)(2)(b) OPTION]

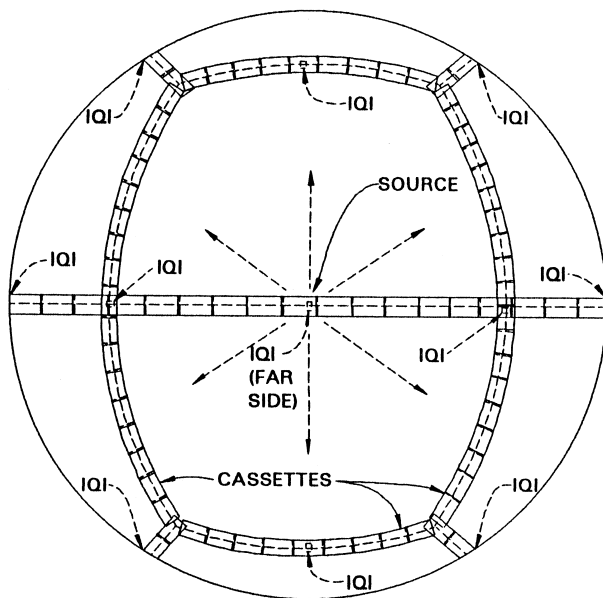


FIG. D-210-5 COMPLETE CIRCUMFERENTIAL
WELDS SPHERICAL COMPONENT
[T-277.2(b)(4)(a) & T-277.2(b)(6)]

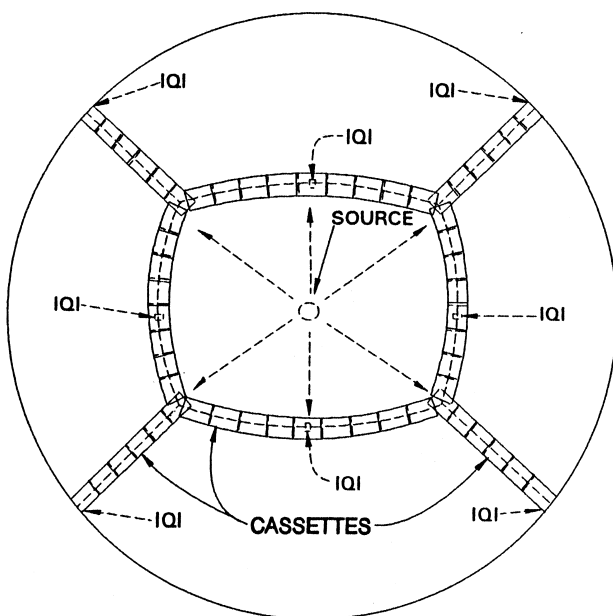


FIG. D-210-7 PLAN VIEW A-A

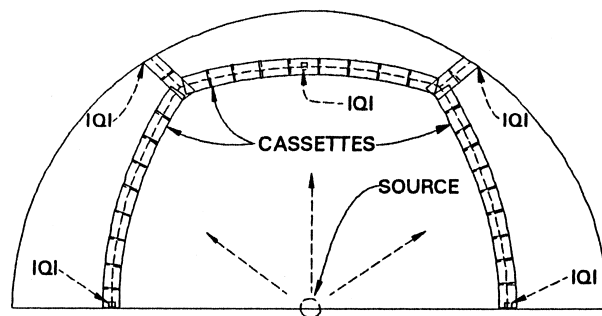
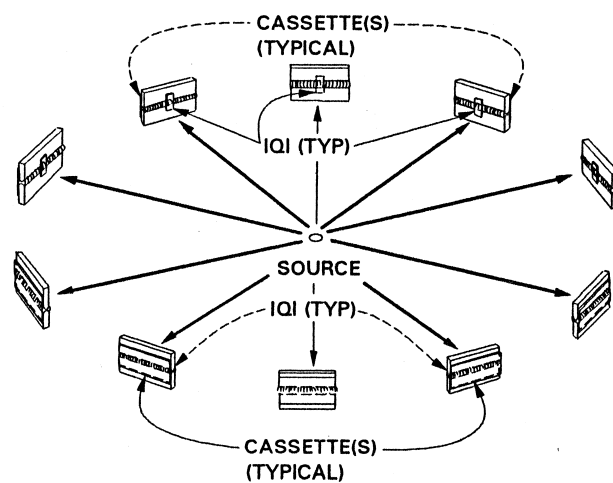


FIG. D-210-6 WELDS IN SEGMENTS OF
SPHERICAL COMPONENT
[T-277.2(b)(5) & T-277.2(b)(5)(b) & T-277.2(b)(6)]



Note: Special Cases IQI Locations are Typical in All Figures.

FIG. D-210-8 ARRAY OF OBJECTS IN A CIRCLE
[T-277.2(b)(7)]

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ARTICLE 4

ULTRASONIC EXAMINATION METHODS FOR INSERVICE INSPECTION

T-410 SCOPE

This Article describes or references requirements which are to be used in selecting and developing [see T-110(c)] ultrasonic examination procedures when examination to any part of this Article is a requirement of a referencing Code Section. These procedures are to be used for the ultrasonic examination and the dimensioning of indications for comparison with acceptance standards when required by the referencing Code Section; the referencing Code Section shall be consulted for specific requirements for the following:

- Personnel Qualification/Certification Requirements
- Procedure Requirements/Demonstration, Qualification, Acceptance
- Examination System Characteristics
- Retention and Control of Calibration Blocks
- Extent of Examination and/or Volume to Be Scanned
- Acceptance Standards to Be Used for Evaluation
- Retention of Records
- Report Requirements

T-420 GENERAL

T-421 Basic Requirements and Terms Used

When this Article is specified by a referencing Code Section, the ultrasonic method described in this Article shall be used together with Article 1, General Requirements. Definitions of terms used in this Article are in Mandatory Appendix III of Article 5.

T-422 Personnel Requirements

The user of this Article shall be responsible for assigning qualified personnel to perform ultrasonic examination to the requirements of this Article. Personnel performing this examination shall be qualified as required by the referencing Code Section.

T-423 Procedure Requirements

Ultrasonic examination shall be performed in accordance with a written procedure.

T-424 General Examination Requirements

T-424.1 Examination Coverage. The volume shall be examined by moving the search unit over the examination volume. As a minimum, each pass of the search unit shall overlap a minimum of 50% of the transducer (piezoelectric element) dimension perpendicular to the direction of the scan. Alternatively, each pass of the search unit shall overlap a dimension less than the minimum beam dimension as determined in Appendix B, B-60, Beam Spread. Oscillation of the search unit is permitted provided improved coverage is demonstrated.

T-424.2 Rate of Search Unit Movement and Pulse Repetition Rate. The ultrasonic instrument pulse repetition rate shall be sufficient to pulse the search unit at least six times within the time necessary to move one-half the transducer (piezoelectric element) dimension parallel to the direction of the scan at maximum scanning speed. Alternatively, a dynamic calibration multiple reflectors that is within $\pm 2\text{dB}$ of a static calibration may be used to verify an acceptable pulse repetition rate.

T-424.3 Scanning Sensitivity Level. For both manual and mechanized examinations, recording of indications shall be made at scan sensitivity. During scanning only the gain or attenuator controls may be adjusted. Any adjustments to the other controls shall require recalibration.

T-430 EQUIPMENT

T-431 Instrument Requirements

T-431.1 Type. A pulse-echo type of ultrasonic instrument shall be used. The instrument shall be equipped

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with a stepped gain control calibrated in units of 2.0 dB or less.

T-434 Search Unit Requirements

T-434.1 Beam Spread Measurement. Measurements of beam spread for scan indexing limits shall be taken only when required by a Referencing Code Section. Measurements of angle beam search units shall be performed once for a search unit wedge combination in the calculated far field at the beginning of each period of extended use (or every 3 months, whichever is less). A technique for beam spread is given in Appendix B, Section B-60. Other techniques may be used.

T-435 Basic Calibration Block(s)

If the qualified procedure calls for a basic calibration block, Appendix J provides a description of one design of block. Other calibration block designs may be used.

T-436 Computerized Imaging Techniques

The major attribute of computerized imaging techniques (CITs) is their effectiveness when used to characterize and evaluate indications; however, CITs may also be used to perform the basic scanning functions required for flaw detection. Computer processed data analysis and display techniques are used in conjunction with automated scanning mechanisms to produce two and three dimensional images of flaws which provides an enhanced capability for examining critical components and structures. Computer processes may then be used to quantitatively evaluate the type, size, shape, location, and orientation of flaws detected by ultrasonic examination or other NDE methods. Descriptions for some techniques that may be used in computerized imaging are provided in Nonmandatory Appendix E.

T-440 REQUIREMENTS

T-441 Vessel Examinations

T-441.1 Scanning Requirements

T-441.1.1 General Scanning Requirements. The volume of weld and adjacent base material (volume on either side of the weld seam) that is to be examined shall be as required by the referencing Code Section. These volumes shall be scanned using qualified techniques.

T-441.1.2 Scan for Interference With Angle Beam Examination. Prior to the initial angle beam

examination, the base material through which the angle beams will travel shall be scanned with a straight beam search unit [(b) below] to detect laminar reflectors which might affect the interpretation of angle beam results. These examination data shall be recorded.

(a) Straight Beam Scanning for Planar Reflectors. The examination for planar reflectors shall be performed on the entire volume of weld and adjacent base material to the extent required by the referencing Code Section. The calibration shall be performed as described in T-462. Penetration shall be verified by obtaining a reflection from an opposite surface of the material being examined when the two surfaces are parallel.

(b) Straight Beam Scanning for Laminar Reflectors. Scanning for laminar reflectors shall be performed at a gain setting that gives an initial back reflection amplitude of 80% ($\pm 5\%$ of full screen height) of screen height from the component. When the examination is performed from the tapered surface at a transition in thickness of the component, angle beam longitudinal waves traveling essentially perpendicular to the back surface may be used to maintain the back reflection.

T-441.1.3 Extent of Scanning. Wherever feasible, the scanning of the examination volume shall be carried out from both sides of the weld on the same surface. Where configuration or adjacent parts of the component are such that scanning from both sides is not feasible, this fact shall be included in the report of the examination.

T-441.1.4 Angle Beam Scanning. The calibration shall be performed as described in T-460. The examination volume shall be scanned with angle beam search units directed both at right angles to the weld axis and along the weld axis. Wherever feasible, each examination shall be performed in two directions, i.e., approaching the weld from opposite directions and parallel to the weld from opposite directions.

T-441.1.5 Scanning for Reflectors Oriented Parallel to the Weld. The angle beam search units shall be aimed at right angles to the weld axis, with the search unit manipulated so that the ultrasonic beams pass through the entire volume of weld metal. The adjacent base metal in the examination volume must be completely scanned by two angle beams, but need not be completely scanned by both angle beams from both directions (any combination of two angle beams will satisfy the requirement). Where the ultrasonic beams are directed essentially normal to the plane of the weld (parallel to the surface of the material, as when the examination is conducted from the nozzle bore or flange face), beam angles sufficient to provide

complete coverage of the weld from one direction shall be acceptable. The additional $\frac{1}{4}$ volume angle beam examination shall comply with these requirements within one-fourth of the thickness from the examination surface.

T-441.1.6 Scanning for Reflectors Oriented Transverse to the Weld. The angle beam search units shall be aimed parallel to the axis of longitudinal and circumferential welds. The search unit shall be manipulated so that the ultrasonic beams pass through all of the examination volume. Scanning shall be done in two directions 180 deg. to each other to the extent possible. Areas blocked by geometric conditions shall be examined from at least one direction. The additional $\frac{1}{4}$ volume angle beam examination shall comply with these requirements within one-fourth of the thickness from the examination surface.

T-441.1.7 Recording Angle Beam Examination Data for Planar Reflectors. Appendix H contains a method of recording angle beam exam data. Other qualified methods may be used.

T-441.1.8 Recording Examination Data for Planar Straight Beam Reflectors. Appendix K contains a method of recording straight beam exam data. Other qualified methods may be used.

T-441.1.9 Recording Straight Beam Examination Data for Laminar Reflectors

(a) *Recording of Laminar Reflectors for Interference With Angle Beam Examination.* Record all areas giving indications equal to or greater than the remaining back reflection.

(b) *Recording of Laminar Reflectors for Acceptance.* Record all areas where one or more discontinuities produce a continuous total loss of back reflection accompanied by continuous indications in the same plane.

(c) *Data Required.* The following data shall be recorded: sweep reading of laminar reflectors from surface, position from reference line, and location parallel to the reference line for each search unit position giving the recordable extent of the indication, as the "laminar" area is scanned on parallel scan paths.

T-442 Examination of Nozzle Inner Radius and Inner Corner Regions

T-442.1 General. This paragraph describes the requirements for ultrasonic examination of nozzle inner radius and inner corner regions. The requirements described here are used on ferritic materials greater than 2 in. (51 mm) in thickness to detect, locate, and

determine the dimensions of reflectors within the examination area.

T-442.2 Surface Preparation. The examination surfaces shall be free of irregularities, loose foreign matter, or coatings which interfere with ultrasonic wave transmission.

T-442.3 Identification of Examination Areas

(a) *Examination Area Locations.* Identification and location shall be shown on an identification plan.

(b) *Marking.* If examination areas are permanently marked by low-stress stamps and/or vibratooling, the marking shall be in accordance with the referencing Code requirements.

(c) *Referencing System.* Each examination area shall be located and identified by a system of referencing points placed on the component. The system shall permit identification of each examination area and designation of regular intervals along the length of the area. A typical system for layout is described in Appendix A; however, a different system may be utilized provided it meets the above requirements.

T-442.4 Scanning Requirements

T-442.4.1 General Scanning Requirements. The examination volume shall be as required by the referencing Code Section. These volumes shall be scanned by qualified ultrasonic techniques. Nonmandatory Appendix F provides guidelines for procedure and technique qualification, but other qualification methods may be used.

T-442.4.2 Scan for Interference With Examination. When examining from the external surfaces and prior to the initial examination, the base material through which the examination beams will travel shall be scanned to detect reflectors which might affect the interpretation of examination results. This examination data shall be recorded.

Scanning for reflectors shall be performed at a gain setting that gives an initial back reflection amplitude of 80% ($\pm 5\%$ of full screen height) of screen height from the component. When the examination is performed from the tapered surface at a transition in thickness of the component, angle beam waves traveling essentially perpendicular to the back surface may be used to maintain the back reflection.

T-442.4.3 Extent of Scanning. Scanning of the entire examination volume shall be performed as possible. Where configurations or adjacent parts of the component are such that scanning the entire area is not feasible, this fact shall be included in the report of the examination.

T-442.4.4 Scanning for Planar Flaws. The examination volume shall be scanned such that the anticipated flaws will be intercepted by the sound beams in a manner that will allow detection. Wherever feasible, each examination shall be performed in two directions.

T-442.4.5 Recording Examination Data for Planar Reflectors Using Amplitude-Based Technique

(a) When amplitude-based technique is used, record all reflectors that produce a response equal to or greater than 20% of the primary reference response (PRR). However, the clad interface metallurgical reflectors and back wall reflections need not be recorded. Record all search unit position and location dimensions to the nearest tenth of an inch.

(b) Obtain data from successive scans at increments no greater than 50% of the transducer dimension measured parallel to the scan increment change at the examination area. Record data for the end points as determined by 20% PRR. Emphasis must be placed on measurement of the parameters determining the reflector length and height and the distances from the examination surface to the top and bottom of the reflector, since these dimensions are the factors most critical in determining ultimate evaluation and disposition of the flaw (see Appendix D for an illustrated example).

(c) The following reflector data shall be recorded when a reflector exceeds 20% PRR.

(1) Maximum percent of PRR, sweep reading of indication, search unit position, and beam direction.

(2) For reflectors 20 to 100% PRR, the minimum sweep reading and the search unit position along the length of the reflector for 20% PRR when approaching the reflector from the maximum signal direction.

(3) For reflectors 20 to 100% PRR, maximum sweep reading and the search unit position along the length of the reflector for 20% PRR when moving away from the reflector's maximum signal direction.

(4) For reflectors exceeding 100% PRR, minimum sweep reading and the search unit position along the length of the reflector for 50% of the maximum amplitude when approaching the reflector from the maximum signal direction.

(5) For reflectors exceeding 100% PRR, minimum sweep reading and the search unit position along the length of the reflector for 50% of the maximum amplitude when moving away from the reflector's maximum signal direction.

(6) The length of the reflector shall be obtained by recording the positions of each end of the reflector at 20% PRR.

T-442.4.6 Recording Examination Data for Planar Reflectors Using Non-Amplitude-Based Techniques. When examinations are performed using non-amplitude-based techniques, indication recording requirements shall be specified in the examination procedure.

T-442.4.7 Recording Data for Reflectors Which Interfere With Examination

(a) Record all areas giving indications equal to or greater than the remaining back reflection.

(b) The following data shall be recorded: sweep reading of reflectors from surface, position from reference, and location parallel to reference for each search unit position giving the recordable extent of the indication.

T-444 Pumps and Valves (Including Welds)

T-444.1 Basic Calibration Blocks. Blocks for pumps and valves shall be in accordance with Appendix J, except that only alternative (c) of Appendix J shall apply.

T-444.2 Examination. Examination shall be made in accordance with T-470, except that T-444.2.1 shall be substituted for T-470.1.1.

T-444.2.1 General. This subparagraph describes the requirements for ultrasonic examination of welds, or base metal repairs, or both, in valves and pumps. Some cast alloys may not be examinable by the techniques given here.

T-444.2.2 Recording. Record reflectors in accordance with T-441.1.7, T-441.1.8, and T-441.1.9.

T-445 Inservice Examination of Bolts and Studs

T-445.1 When inservice examination of bolts and studs is specified by the referencing Code Section, the examination shall be performed in accordance with Appendix L.

T-445.2 For materials with diameters 2 in. (51 mm) and greater, basic calibration blocks shall have reflectors in accordance with Appendix L.

T-445.3 For bolts and studs less than 2 in. in diameter, a calibration block shall be made to the requirements of Appendix L, except for the size of the reflectors. The reflector area shall be established as one thread depth for the threads used on the bolt or stud. The area of the reflector is determined by the depth of a

straight notch and the resulting length of the notch. Any of the types of notches illustrated in Appendix L, Fig. L-13-1 may be used as long as the area does not exceed that calculated for a straight notch one thread depth deep.

T-445.4 Any discontinuity which causes an indication in excess of that produced by the calibration reflector shall be investigated. The shape, identity, and location of all such reflectors shall be evaluated in terms of the acceptance-rejection standards of the referencing Code Section.

T-450 PROCEDURE REQUIREMENTS

Ultrasonic examination shall be performed in accordance with a written procedure. Each procedure shall include the following information with a single value or range of values as applicable:

- (a) weld types and configurations to be examined, including thickness dimensions, materials, and product form (casting, forging, plate, etc.);
- (b) the surface or surfaces from which the examination shall be performed;
- (c) surface condition requirements;
- (d) couplant brand name or type;
- (e) technique (straight beam, angled beam, contact and/or immersion) used for detection and sizing;
- (f) angles and mode(s) of wave propagation in the material;
- (g) search unit type, frequency, and transducer size(s) minimum/maximum pulse repetition rate;
- (h) special search units, wedges, shoes, or saddles, type, maximum length of search unit cable;
- (i) ultrasonic instrument type(s) including manufacturer and model or series of pulser, receiver, and amplifier;
- (j) description of calibration blocks and technique(s) for detection and sizing;
- (k) beam directions, extent of scanning maximum scan speed, scanning pattern and steps;
- (l) minimum data to be recorded and method of recording (manual or automatic) minimum sampling rate for automatic;
- (m) automatic alarm and recording equipment, or both (e.g., strip chart, analog tape, digitizing);
- (n) rotating, revolving, or scanning mechanisms, if used;
- (o) personnel qualification requirements;
- (p) describe the demonstration or qualification of the procedure used to detect and size flaws as required by the referencing Code Section;

(q) method and criteria for discriminating geometric from flaw indications;

(r) method and criteria for length and depth sizing of flaws;

(s) minimum calibration data to be recorded;

(t) identification of qualification specimen;

(u) identification of essential variables and range of qualification.

T-460 CALIBRATION

T-461 Instrument Calibration

The requirements of T-461.1 and T-461.2 shall be met at the beginning and end of the weld examinations performed during one outage.

T-461.1 Screen Height Linearity. The ultrasonic instrument shall provide linear vertical presentation within $\pm 5\%$ of the full screen height for at least 80% of the calibrated screen height [base line to maximum calibrated screen point(s)]. The procedure for evaluating screen height linearity is provided in Appendix I and shall be performed at the beginning of each period of extended use (or every 3 months, whichever is less).

T-461.2 Amplitude Control Linearity. The ultrasonic instrument shall utilize an amplitude control, accurate over its useful range to $\pm 20\%$ of the nominal amplitude ratio, to allow measurement of indications beyond the linear range of the vertical display on the screen. The procedure for evaluating amplitude control linearity is given in Appendix II.

T-462 System Calibration (General)

Calibration includes all those actions required to assure that the sensitivity and accuracy of the signal amplitude and time outputs of the examination system (whether displayed, recorded, or automatically processed) are repeated from examination to examination.

Calibration may be by use of basic calibration blocks with artificial or defect reflectors.

Methods are provided in Appendices B and C.

Other methods of calibration may include sensitivity adjustment based on the examination material, etc.

T-470 EXAMINATION

T-471 Examination of Vessel Welds

T-471.1 General. This paragraph describes the requirements for ultrasonic examination of vessel welds

and/or base metal repairs. The requirements described here are used on ferritic materials greater than 2 in. (51 mm) in thickness to detect, locate, and dimension indications within the weld or weld repaired base materials and adjacent base material.

T-471.1.2 Surface Preparation. The examination surfaces shall be free of irregularities, loose foreign matter, or coatings which interfere with ultrasonic wave transmission.

T-471.1.3 Uniform Technique for Identification of Examination Areas

(a) *Weld Locations.* Weld identification and location shall be shown on a weld identification plan.

(b) *Marking.* If welds are to be permanently marked, low stress stamps and/or vibratooling may be used. Markings applied after final stress relief of the component shall not be any deeper than $\frac{3}{64}$ in. (1.2 mm).

(c) *Reference System.* Each weld and examination area shall be located and identified by a system of reference points. The system shall permit identification of each weld center line and designation of regular intervals along the length of the weld. A general system for layout of vessel welds is described in Appendix A; however, a different system may be utilized provided it meets the above requirements.

T-480 EVALUATION

T-481 General

It is recognized that not all ultrasonic reflectors indicate flaws, since certain metallurgical discontinuities and geometric conditions may produce indications that are not relevant. Included in this category are plate segregates in the heat affected zone that become reflective after fabrication. Under straight beam examination, these may appear as spot or line indications. Under angle beam examination, indications that are determined to originate from surface conditions (such as weld root geometry) or variations in metallurgical structure in stainless steel materials (such as the automatic-to-manual weld clad interface) may be classified as geometric indications. The identity, maximum amplitude, location, and extent of reflector causing a geometric indication shall be recorded. (For example: internal attachment, 200% DAC, 1 in. above weld center line, on the inside surface, from 90 to 95 deg.) The following steps shall be taken to classify an indication as geometric:

(a) interpret the area containing the reflector in accordance with the applicable examination procedure;

(b) plot and verify the reflector coordinates. Prepare a cross-sectional sketch showing the reflector position and surface discontinuities such as root and counterbore; and

(c) review fabrication or weld preparation drawings. Other ultrasonic techniques or nondestructive examination methods may be helpful in determining a reflector's true position, size, and orientation.

T-482 Evaluation of Reflectors

T-482.1 Evaluation of Planar Reflectors

T-482.1.1 Reflectors shall be evaluated in accordance with a qualified procedure.

T-482.2 Evaluation of Laminar Reflectors

T-482.2.1 Evaluation of Laminar Reflectors for Interference With Angle Beam Examinations. Data recorded as required in T-441.1.9(a) and (c) represent the dimensions of the reflector needed to determine interference with angle beam examinations. Where laminar reflectors interfere with the scanning of examination volumes for planar reflectors, the angle beam examination technique shall be modified to examine the maximum feasible volume, within the specified examination volume, and the description of the volume excluded by the lamination shall be noted in the record of the examination [T-492(e)].

T-482.2.2 Evaluation of Laminar Reflectors for Acceptance. Data recorded as required in T-441.1.2.9(b) and (c) represent the dimensions of the reflector.

T-483 Alternative Evaluations

Reflector dimensions exceeding the referencing Code Section requirements may be evaluated to any alternative standards as may be provided by the referencing Code Section.

T-490 RECORDS

T-491 Calibration Records

Instrument calibrations (T-461) shall be included in the ultrasonic calibration records. Ultrasonic examination system calibration requirements and identity of calibration block, if used, shall be included in the ultrasonic calibration records.

T-492 Examination Records

For each ultrasonic examination, the following information shall be identified and recorded:

- (a) procedure;
- (b) ultrasonic examination system (equipment);
- (c) examination personnel identity and level if required by referencing Code Section;
- (d) calibration sheet identity;
- (e) identification and location of weld or volume scanned;
- (f) surface from which examination was conducted;
- (g) map or record of indications detected or areas cleared;
- (h) date and time examinations were performed;
- (i) couplant used, brand name, or type;
- (j) identification of basic calibration block (if used);
- (k) surface condition;

- (l) frequency(ies), and
- (m) special equipment.

T-493 Evaluation Record

Records of any evaluations of indications shall be maintained and documented.

T-494 Report

A report of the examinations shall be made. The report shall include a record indicating the weld(s) or volume examined (this may be marked-up drawings or sketches), the location of each recorded reflector, and the identification of the operator who carried out each examination or part thereof as detailed in T-490. The report shall be filed and maintained in accordance with the referencing Code Section.

ARTICLE 4

MANDATORY APPENDICES

APPENDIX I — SCREEN HEIGHT LINEARITY

To verify the ability of the ultrasonic instrument to meet the linearity requirement of T-461.1, position an angle beam search unit as shown in Fig. I-1 so that indications can be observed from both the $\frac{1}{2}$ and $\frac{3}{4}T$ holes in a basic calibration block. Adjust the search unit position to give a 2:1 ratio of amplitudes between the two indications, with the larger set at 80% of full screen height. Without moving the search unit, adjust sensitivity (gain) to successively set the larger indication from 100% to 20% of full screen height, in 10% increments (or 2 dB steps if a fine control is not available), and read the smaller indication at each setting. The reading must be 50% of the larger amplitude, within 5% of full screen height. The settings and readings must be estimated to the nearest 1% of full screen. Alternatively, a straight beam search unit may be used on any calibration block which will provide amplitude differences, with sufficient signal separation to prevent overlapping of the two signals.

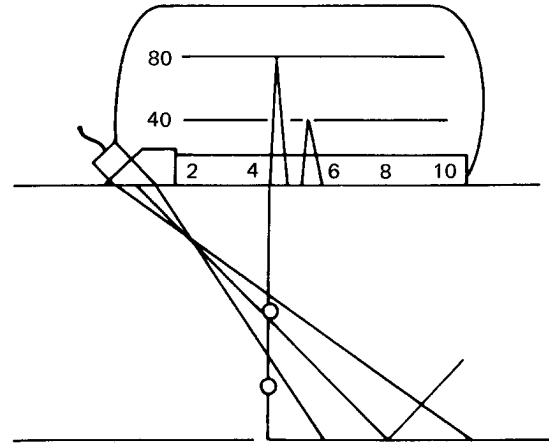


FIG. I-1 LINEARITY

APPENDIX II — AMPLITUDE CONTROL LINEARITY

To verify the accuracy of the amplitude control of the ultrasonic instrument, as required in T-461.2, position an angle beam search unit as shown in Fig. I-1 so that the indication from the $\frac{1}{2}T$ hole in a basic calibration block is peaked on the screen. With the increases and

decreases in attenuation shown in the following table, the indication must fall within the specified limits. Other convenient reflectors from any calibration block may be used with angle or straight beam search units.

Indication Set at % of Full Screen	dB Control Change	Indication Limits % of Full Screen
80%	-6 dB	32 to 48%
80%	-12 dB	16 to 24%
40%	+6 dB	64 to 96%
20%	+12 dB	64 to 96%

The settings and readings must be estimated to the nearest 1% of full screen.

ARTICLE 4

NONMANDATORY APPENDICES

APPENDIX A — LAYOUT OF VESSEL REFERENCE POINTS

The layout of the weld shall consist of placing reference points on the center line of the weld. The standard spacing of the reference points shall be 12 in. All points shall be identified with their numbers: 0, 1, 2, 3, 4, etc. The numbers of points, distance apart, and starting point shall be recorded on the reporting form. The weld center line shall be the divider for the two examination surfaces.

(a) *Circumferential (Girth) Welds.* The standard starting point shall be vessel 0 deg. The reference points shall be numbered clockwise, as viewed from the top of the vessel. The examination surfaces shall be identified as above or below the weld.

(b) *Longitudinal (Vertical) Welds.* Longitudinal welds shall be laid out from the center line of circumferential welds at the top end of the weld. The examination surface shall be identified as clockwise or counterclockwise as viewed from the top of the vessel.

(c) *Nozzle-to-Vessel Welds.* The external reference circle shall have a sufficient whole number of inches radius so that the circle falls on vessel external surface beyond the weld fillet. The internal reference circle shall have a sufficient whole number of inches radius so that the circle falls within $\frac{1}{2}$ in. (13 mm) of the weld center line. Zero deg. point on the weld will be the top of the nozzle. The 0 deg. point for welds of nozzles centered in heads shall be located at the 0 deg. axis of the vessel. Angular layout of the weld shall be made clockwise on the external surface, counterclockwise on the internal surface. Zero degree, 90 deg., 180 deg., and 270 deg. lines will be marked on all nozzle welds examined; 30 deg. increment lines will be marked on nozzle welds greater than 4 in. (102 mm) radius; 15 deg. increment lines will be marked on nozzle welds greater than 12 in. (305 mm) radius; 5 deg. increment lines will be marked on nozzle welds greater than 24 in. (610 mm) radius.

APPENDIX B — GENERAL TECHNIQUES FOR ANGLE BEAM CALIBRATIONS

Descriptions and figures for the general method relate position and depth of the reflector to eighths of the V-path. The sweep range may be calibrated in terms of units of metal path,¹ projected surface distance or actual depth to the reflector (as shown in Fig. B-10). The particular method may be selected according to the preference of the examiner.

B-1 GENERAL REQUIREMENTS

Calibration shall include the complete ultrasonic examination system. The original calibration must be performed on the basic calibration block. Checks shall be made to verify the sweep range calibration and distance amplitude correction. Checks shall include the entire examination system.

In all calibrations, it is important that maximum indications be obtained with the sound beam oriented perpendicular to the axis of the side-drilled holes and notches. The center line of the search unit shall be at least $1\frac{1}{2}$ in. (38 mm) from the nearest side of the block (rotation of the beam into the corner formed by the hole and the side of the block may produce a higher amplitude at a longer beam path; this beam path shall not be used for calibration). For contact examination, the temperature of the examination and basic calibration block surfaces shall be within 25°F (14°C). For immersion examination, the couplant temperature for calibration shall be within 25°F (14°C) of the couplant temperature used in actual scanning, or appropriate compensations for angle and sensitivity changes shall be made.

¹ Reflections from concentric cylindrical surfaces such as provided by some IIW blocks and the AWS distance calibration block may be used to adjust delay zero and sweep range for metal path calibration.

B-2 CALIBRATION CHECK UPON CHANGE IN THE COMPLETE ULTRASONIC EXAMINATION SYSTEM

Alternate cables and search units singly and in combination that have been included in a prior system calibration may be later substituted in the system; such substitution shall not necessitate a calibration check. When any other part of the examination system is changed, a calibration check shall be made on the basic calibration block or on the simulator, provided the simulation is subsequently compared to the basic calibration block to verify that $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}T$ points on the sweep and distance amplitude correction values recorded satisfy the requirements of Appendix B-71 and Appendix B-72.

B-3 CALIBRATION CHECK ON BASIC CALIBRATION BLOCK OR SIMILAR CHECK

A calibration check on at least three of the basic reflectors in the basic calibration block or a check on at least three of the simulation reflectors in the simulation block shall be made at the finish of each examination. Interim calibration checks may be made as above or on the three required pulses from the electronic simulator every 12 hr during the examination and when examination personnel (except for mechanized examinations) are changed.

When a simulator is used, a minimum of three pulses shall be used to simulate the original calibration performed on the basic calibration block. The three pulses shall be within the ranges of 15% to 20%, 40% to 60%, and 70% to 110% of the maximum calibrated metal path. Simulator block reflectors and/or electronic simulator settings shall be recorded in the written calibration record. When an electronic simulator is used, it shall be electronically calibrated at least every 6 months to verify compliance with the manufacturer's specification. The sweep and distance-amplitude correction values recorded shall satisfy the requirements of Appendix B-71 and Appendix B-72.

B-4 SIMULATOR CHECK

Any simulator checks that are used must be correlated with the original calibration on the basic calibration block during the original calibration. The simulator checks may use different types of calibration blocks (such as IIW) and/or electronic simulation. However,

the simulation used shall be completely identifiable on the calibration sheet(s). The simulator check shall be made on the entire examination system. The entire system does not have to be tested in one check. As an example, the transducer sensitivity and electronic instrument could be evaluated in separate tests.

B-5 CALIBRATION MEASUREMENTS

Each calibration shall be performed from the surface (clad or unclad) corresponding to the surface of the component from which the examination will be performed.

B-6 TECHNIQUES

Appendix B provides general techniques for angle beam calibration. Other techniques may be used. Any control which affects the instrument linearity (e.g., filters, reject, or clipping), shall be in the same position for calibration linearity checks and examination.

B-7 ANGLE BEAM CALIBRATION

The calibration shall provide the following measurements:

- (a) sweep range calibration;
- (b) distance-amplitude correction;
- (c) position calibration;
- (d) echo amplitude measurement from the surface notch in the basic calibration block;
- (e) when an electronic distance amplitude correction device is used, the primary reference response shall be equalized at a nominal constant screen height at or between 40% to 80% of full screen height over the distance range to be employed in the examination.

B-8 INNER $\frac{1}{4}$ VOLUME

(a) The additional $\frac{1}{4}$ volume angle calibration requirement may be satisfied by using one or more beams as required to calibrate on $\frac{1}{8}$ in. (3.2 mm) maximum diameter side drilled holes in that volume.

(b) When the examination is performed from the outside surface, calibrate on the $\frac{1}{8}$ in. (3.2 mm) diameter side drilled holes to provide the shape of the DAC from $\frac{1}{2}$ in. (13 mm) to $\frac{1}{4}$ depth, but set gain on the Code hole at $\frac{1}{4}$.

(c) When the examination is performed from the inside surface, calibrate on the $\frac{1}{8}$ in. (3.2 mm) diameter

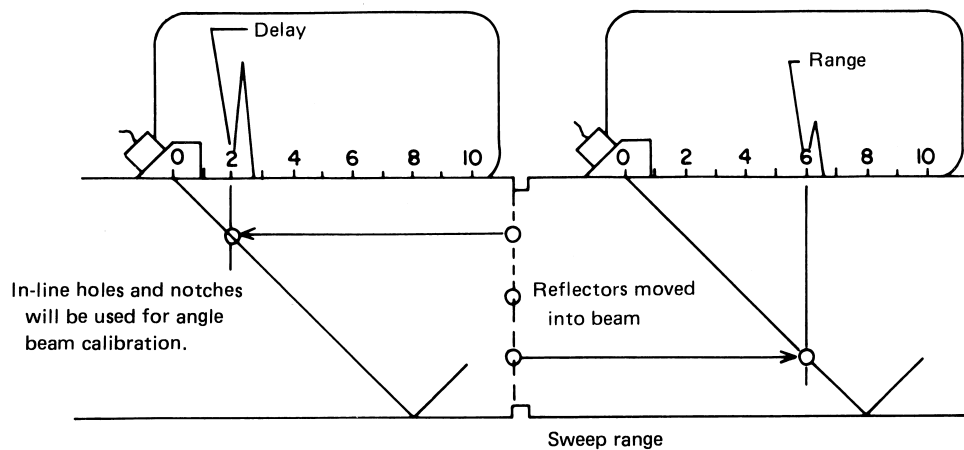


FIG. B-10 SWEEP RANGE

side drilled holes to provide the shape of the DAC and the gain setting.

B-10 SWEEP RANGE CALIBRATION (SEE FIG. B-10)

(a) Position the search unit for the maximum first indication from the $\frac{1}{4}T$ side-drilled hole. Adjust the left edge of this indication to line 2 on the screen with the delay control.

(b) Position the search unit for the maximum indication from the $\frac{3}{4}T$ hole. Adjust the left edge of this indication to line 6 on the screen with the range control.

(c) Repeat delay and range control adjustments until the $\frac{1}{4}T$ and $\frac{3}{4}T$ hole reflections start at sweep lines 2 and 6.

(d) Position the search unit for maximum response from the square notch on the opposite surface. The indication will appear near sweep line 8.

(e) Two divisions on the sweep equal $\frac{1}{4}T$.

B-20 DISTANCE-AMPLITUDE CORRECTION (PRIMARY REFERENCE LEVEL) (SEE FIG. B-20)

B-21 Calibration From the Clad Side

(a) Position the search unit for maximum response from the hole which gives the highest amplitude.

(b) Adjust the sensitivity control to provide an 80% ($\pm 5\%$ of full screen height) of full screen indication

from the hole. Mark the peak of the indication on the screen.

(c) Position the search unit for maximum response from another hole indication.

(d) Mark the peak of the indication on the screen.

(e) Position the search unit for maximum amplitude from the third hole indication and mark the peak on the screen.

(f) Position the search unit for maximum amplitude from the $\frac{3}{4}T$ hole indication after the beam has bounced from the opposite surface. The indication should appear at sweep line 10. Mark the peak on the screen for the $\frac{5}{4}T$ position.

(g) Connect the screen marks for the side-drilled holes to provide the distance-amplitude curve.

(h) For calibration correction for perpendicular reflectors at the opposite surface, refer to B-50.

B-22 Calibration From the Unclad Side

(a) From the clad side of the block, determine the dB change in amplitude between the $\frac{3}{4}T$ and $\frac{5}{4}T$ positions.

(b) From the unclad side, perform calibrations as noted in B-21 (a) through (e).

(c) To determine the amplitude for the $\frac{5}{4}T$ hole, position the search unit for maximum amplitude from the $\frac{3}{4}T$ hole. Decrease the signal amplitude by the number of dB determined in (a) above. Mark the height of this signal amplitude at sweep line 10 ($\frac{5}{4}T$).

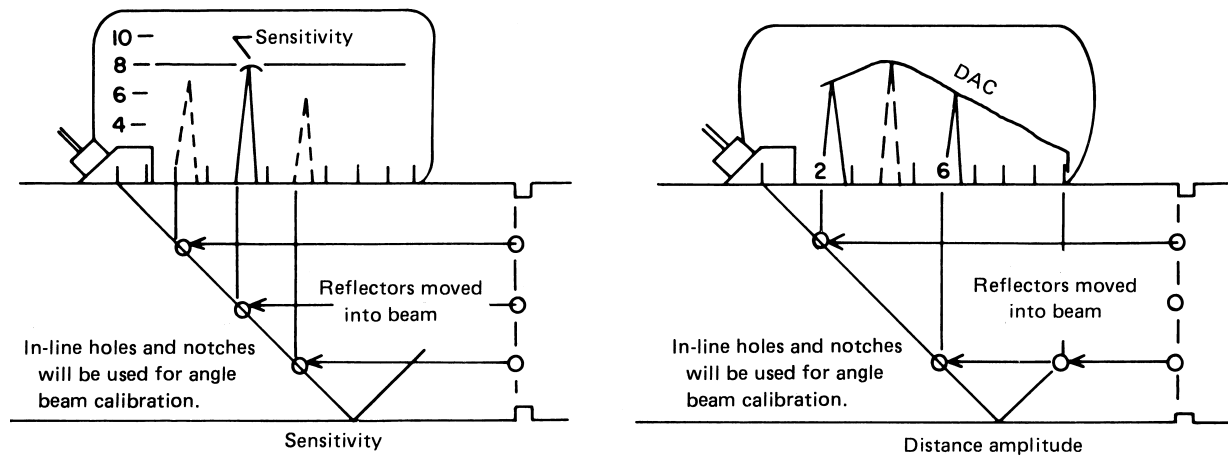


FIG. B-20 SENSITIVITY AND DISTANCE-AMPLITUDE CORRECTION

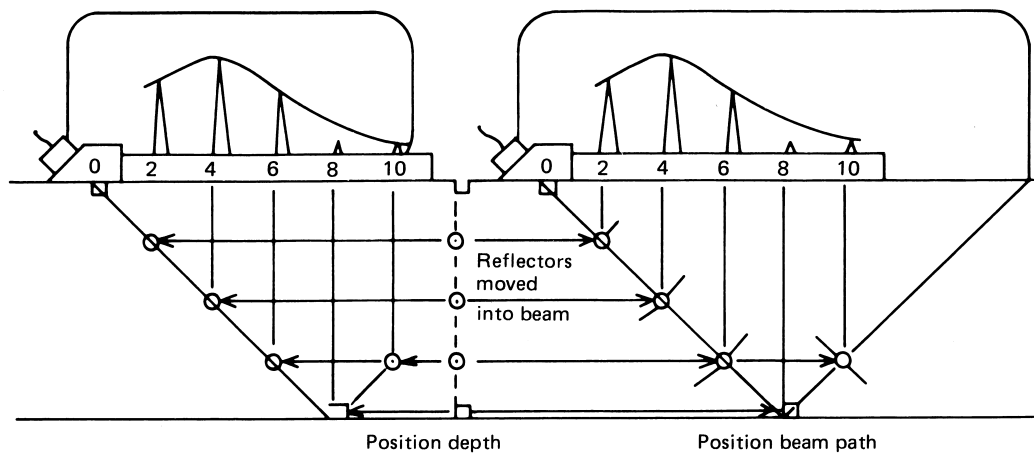


FIG. B-40 POSITION DEPTH AND BEAM PATH

(d) Connect the screen marks to provide the distance-amplitude curve. This will permit evaluation of indications down to the clad surface (near sweep line 8).

(e) For calibration correction for perpendicular planar reflectors near the opposite surface, refer to B-50.

B-40 POSITION CALIBRATION (SEE FIG. B-40)

The following measurements may be made with a ruler, scale, or marked on an indexing strip.²

(a) Position the search unit for maximum response from the $\frac{1}{4}T$ hole. Place one end of the indexing strip against the front of the search unit, the other end extending in the direction of the beam. Mark the number 2 on the indexing strip at the scribe line which is directly above the hole. (If the search unit covers the scribe line, the marks may be made on the side of the search unit.)

(b) Position the search unit for maximum indications from the $\frac{1}{2}T$ and $\frac{3}{4}T$ holes. Keep the same end of the indexing strip against the front of the search unit. Mark the numbers 4 and 6 on the indexing strip at the scribe line.

(c) If possible, position the search unit so that the beam bounces from the opposite surface to the $\frac{3}{4}T$ hole. Mark the number 10 on the indexing strip at the scribe line.

(d) Position the search unit for the maximum opposite surface notch indication. Mark the number 8 on the indexing strip at the scribe line.

(e) The calibration numbers on the indexing strip indicate the position directly over the reflector in sixteenths of the V-path.

(f) The depth from the examination surface to the reflector is T at 8, $\frac{3}{4}T$ at 6 and 10, $\frac{1}{2}T$ at 4, $\frac{1}{4}T$ at 2, and 0 at 0. Interpolation is possible for smaller increments of depth. This measurement may be corrected by the radius of the hole if the radius is considered significant to the accuracy of reflector's location.

²The balance of the calibrations in this Appendix is written based upon the use of the indexing strip. However, the procedures may be transformed for other methods of measurement at the discretion of the examiner.

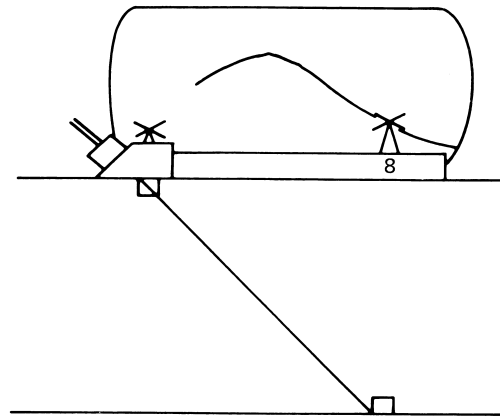


FIG. B-50 PLANAR REFLECTIONS

B-50 CALIBRATION CORRECTION FOR PLANAR REFLECTORS PERPENDICULAR TO THE EXAMINATION SURFACE AT OR NEAR THE OPPOSITE SURFACE (SEE FIG. B-50)

The 45 deg. angle beam shear wave reflects well from a corner reflector. However, mode conversion and redirection of reflection occurs to part of the beam when a 60 deg. angle beam shear wave hits the same reflector. This problem also exists to a lesser degree throughout the 50 deg. to 70 deg. angle beam shear wave range. This correction is required in order to be equally critical of such an imperfection regardless of the examination beam angle.

(a) Position the search unit for maximum amplitude from the square notch on the opposite surface. "X" mark the peak of the indication on the screen near sweep line 8.

(b) The opposite surface square notch may give an indication 2 to 1 above DAC at 45 deg. and $\frac{1}{2}$ DAC at 60 deg. Therefore, the indications from the square notch must be considered when evaluating reflectors at the opposite surface.

B-60 BEAM SPREAD (SEE FIG. B-60)

Measurements of beam spread shall be made on the hemispherical bottom of the round bottom hole. The half maximum amplitude limit of the primary lobe of the beam shall be plotted by manipulating the search unit for measurements on reflections from the round bottom holes as follows.

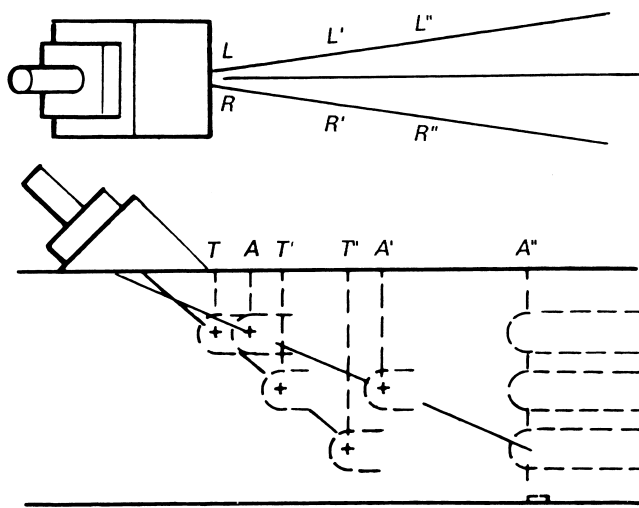


FIG. B-60 BEAM SPREAD

(a) Set the maximum amplitude from the $\frac{1}{4}T$ hole at 80% of full screen. Move search unit toward the hole until indication equals 40% of full screen. Mark beam center line "toward" position on the block.

(b) Set the maximum amplitude from the $\frac{1}{4}T$ hole at 80% of full screen. Move search unit away from the hole until indication equals 40% of full screen. Mark beam center line "away" position on the block.

(c) Position the search unit for 80% of roll screen amplitude from the $\frac{1}{4}T$ hole. Move search unit right without pivoting the beam toward the reflector until the indication equals 40% of full screen. Mark the beam center line "right" position on the block.³

(d) Move the search unit left without pivoting the beam toward the reflector until the indication equals 40% of full screen. Mark the beam center line "left" position on the block.³

(e) Repeat setting and measurements of "toward," "away," "right," and "left" limits of the beam on the $\frac{1}{2}T$ and $\frac{3}{4}T$ round bottom holes.

(f) Record the dimensions from "toward" to "away" and from "right" to "left" positions marked on the block for the $\frac{1}{4}T$ and $\frac{3}{4}T$ round bottom holes.

(g) The smallest of the three "toward" to "away" dimensions shall not be exceeded when indexing between scans perpendicular to the beam direction.

³When manually positioning the search unit, a straight edge may be used to guide the search unit while moving to the right and left to assure that axial positioning and beam alignment are maintained.

(h) The smallest of the three "right" to "left" dimensions shall not be exceeded when indexing between scans parallel to the beam direction.

(i) The projected beam spread angle determined by these measurements shall be used to determine limits as required at other metal paths.

NOTE: If laminar reflectors are present in the basic calibration block, the beam spread readings may be affected; if this is the case, beam spread measurements must be based on the best available readings.

B-70 CALIBRATION CONFIRMATION

Calibration shall be performed prior to use of the system in the thickness range under examination. A calibration check shall verify the sweep range and distance amplitude correction as defined in B-71 and B-72.

B-71 Sweep Range Calibration

If any point on the DAC curve has moved on the sweep line more than 10% of the sweep division reading, correct the sweep range calibration and note the correction in the examination record. If recordable reflectors (T-458) are noted on the data sheets, those data sheets shall be voided, a new calibration shall be recorded, and the voided examinations shall be repeated.

B-72 DAC Correction

If any point on the distance-amplitude correction (DAC) curve has decreased 20% or 2 dB of its amplitude, all data sheets since the last calibration or calibration check shall be marked void. A new calibration shall be made and recorded and the voided examination areas shall be reexamined. If any point on the distance-amplitude correction (DAC) curve has increased more than 20% or 2 dB of its amplitude, all recorded indications since the last valid calibration or calibration check shall be evaluated with the corrected calibration, and their values shall be changed on the data sheets.

APPENDIX C — GENERAL TECHNIQUES FOR STRAIGHT BEAM CALIBRATIONS

C-1 GENERAL REQUIREMENTS

Calibration shall include the complete ultrasonic examination system. The original calibration must be performed on the basic calibration block. Checks shall be made to verify the sweep range calibration and

distance amplitude correction. Checks shall include the entire examination system.

In all calibrations, it is important that maximum indications be obtained with the sound beam oriented perpendicular to the axis of the side-drilled holes and notches. The center line of the search unit shall be at least 1½in. (38 mm) from the nearest side of the block (rotation of the beam into the corner formed by the hole and the side of the block may produce a higher amplitude at a longer beam path; this beam path shall not be used for calibration). For contact examination, the temperature of the examination and basic calibration block surfaces shall be within 25°F (14°C). For immersion examination, the couplant temperature for calibration shall be with 25°F (14°C) of the couplant temperature used in actual scanning, or appropriate compensations for angle and sensitivity changes shall be made.

C-2 CALIBRATION CHECK UPON CHANGE IN THE COMPLETE ULTRASONIC EXAMINATION SYSTEM

Alternate cables and search units singly and in combination that have been included in a prior system calibration may be later substituted in the system: such substitution shall not necessitate a calibration check. When any other part of the examination system is changed, a calibration check shall be made on the basic calibration block to verify that ¼, ½, and ¾T points on the sweep and distance amplitude correction values recorded satisfy the requirements of Appendix C-31 and Appendix C-32.

C-3 CALIBRATION CHECK ON BASIC CALIBRATION BLOCK OR SIMULATOR CHECK

A calibration check on at least three of the basic reflectors in the basic calibration block or a check on at least three of the simulation reflectors in the simulation block shall be made at the finish of each examination. Interim calibration checks may be made as above or on the three required pulses from the electronic simulator every 12 hr during the examination and when examination personnel (except for mechanized examinations) are changed.

When a simulator is used, a minimum of three pulses shall be used to simulate the original calibration performed on the basic calibration block. The three uses shall be within the ranges of 15 to 20%, 40 to

60%, and 70 to 110% of the maximum calibrated metal path. Simulator block reflectors and/or electronic simulator settings shall be recorded in the written calibration record. When an electronic simulator is used, it shall be electronically calibrated at least every 6 months to verify compliance with the manufacturer's specification. The sweep and distance–amplitude correction values recorded satisfy the requirements of Appendix C-31 and Appendix C-32.

C-4 SIMULATOR CHECK

Any simulator checks that are used must be correlated with the original calibration on the basic calibration block during the original calibration. The simulator checks may use different types of calibration blocks (such as IIW) and/or electronic simulation. However, the simulation used shall be completely identifiable on the calibration sheet(s). The simulator check shall be made on the entire examination system. The entire system does not have to be tested in one check. As an example, the transducer sensitivity and electronic instrument could be evaluated in separate tests.

C-5 CALIBRATION MEASUREMENTS

Each calibration shall be performed from the surface (clad or unclad) corresponding to the surface of the component from which the examination will be performed.

C-6 TECHNIQUES

This Appendix provides general techniques for straight-beam calibration. Other techniques may be used. Any control which affects the instrument linearity (e.g., filters, reject, or clipping) shall be in the same position for calibration, linearity check, and examination.

C-7 STRAIGHT BEAM CALIBRATION

The method of calibration shall provide the following measurements (Appendix C gives a general technique):

(a) sweep range calibration;

(b) distance–amplitude correction;

(c) when an electronic distance amplitude correction device is used, the primary reference response shall be equalized at a nominal constant screen height at or between 40% to 80% of full screen height over the distance range to be employed in the examination.

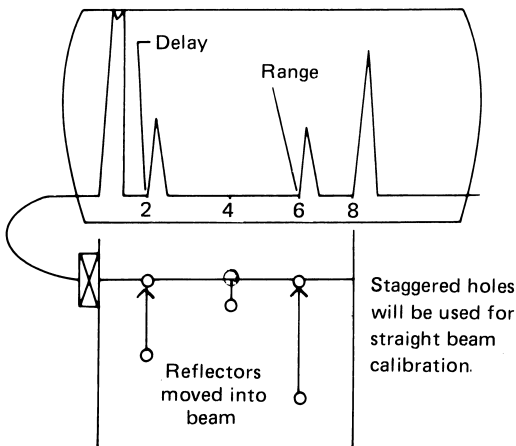


FIG. C-10 SWEEP RANGE

C-10 SWEEP RANGE CALIBRATION⁴ (SEE FIG. C-10)

(a) Position the search unit for the maximum first indication from the $\frac{1}{4}T$ side-drilled hole. Adjust the left edge of this indication to line 2 on the screen with the delay control.

(b) Position the search unit for the maximum indication from $\frac{3}{4}T$ hole. Adjust the left edge of this indication to line 6 on the screen with the range control.

(c) Repeat delay and range control adjustments until the $\frac{1}{4}T$ and $\frac{3}{4}T$ hole reflections start at sweep lines 2 and 6.

C-20 DISTANCE-AMPLITUDE CORRECTION (SEE FIG. C-20)

(a) Position for maximum response from the hole which gives the highest amplitude.

(b) Adjust the sensitivity control to provide an 80% ($\pm 5\%$ of full screen height) of full screen indication from the hole. Mark the peak of the indication on the screen with a grease pencil or other suitable marker.

(c) Position the search unit for maximum response from another hole indication.

(d) Mark the peak of the indication on the screen.

⁴Calibration by beam path measurement may be used by range control positioning by the block back reflection to the sweep division number (or multiple) equal to the measured thickness. The $\frac{1}{4}T$ hole indication must be delay control positioned to $\frac{1}{4}$ of the sweep division number.

(e) Position the search unit for maximum amplitude from the third hole indication and mark the peak on the screen.

(f) Connect the screen marks and extend through the thickness to provide the distance-amplitude curve for the side-drilled holes.

C-30 CALIBRATION CONFIRMATION

Calibration shall be performed prior to use of the system in the thickness range under examination. A calibration check shall verify the sweep range and distance amplitude correction as defined in C-31 and C-32.

C-31 Sweep Range Calibration

If any point on the DAC curve has moved on the sweep line more than 10% of the sweep division reading, correct the sweep range calibration and note the correction in the examination record. If recordable reflectors (T-480) are noted on the data sheets, those data sheets shall be voided, a new calibration shall be recorded, and voided examinations shall be repeated.

C-32 DAC Correction

If any point on the distance-amplitude correction (DAC) curve has decreased 20% or 2 dB of its amplitude, all data sheets since the last calibration or calibration check shall be marked void. A new calibration shall be made and recorded and the voided examination areas shall be reexamined. If any point on the distance-amplitude correction (DAC) curve has increased more than 20% or 2 dB of its amplitude, all recorded indications since the last valid calibration or calibration check shall be evaluated with the corrected calibration and their values shall be changed on the data sheets.

APPENDIX D — DATA RECORD EXAMPLE FOR A PLANAR REFLECTOR

D-10 RECORDING DATA (SEE FIG. D-10)

This Appendix represents an example of the data required to dimension a 120% DAC reflector found when scanning perpendicular to a weld. Figure D-10 is an illustration of the maximum amplitude scan and

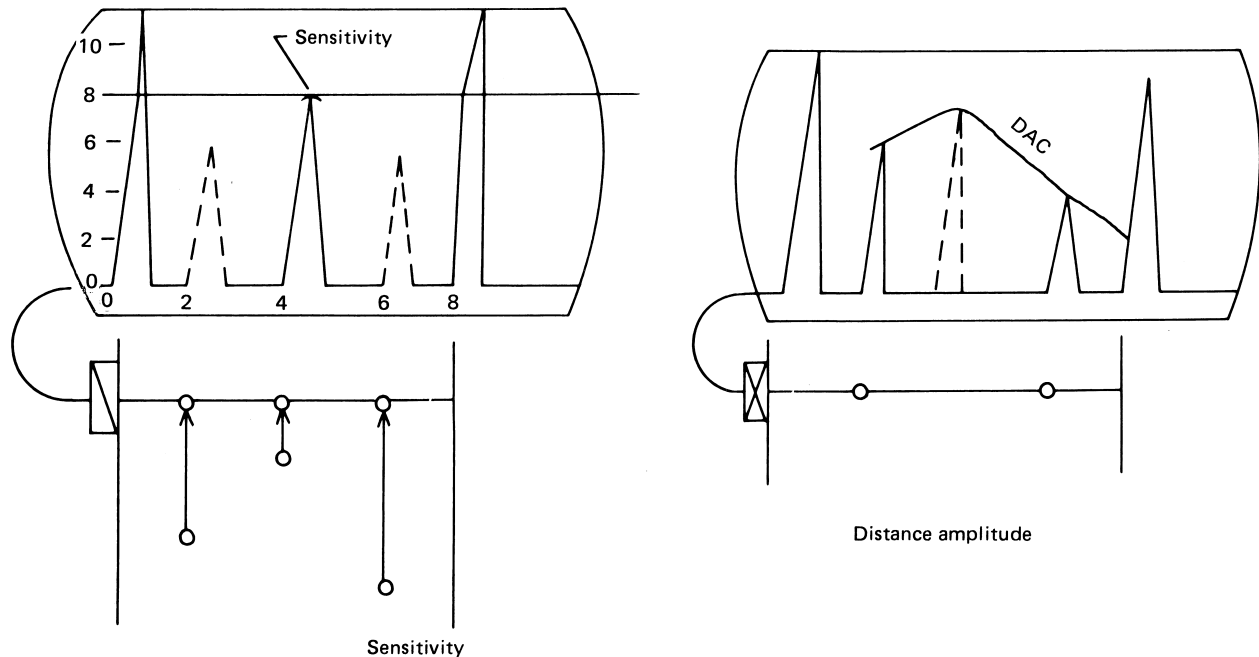


FIG. C-20 SENSITIVITY AND DISTANCE-AMPLITUDE CORRECTION

tabulation of that data with additional scan data that might be taken on the reflector.

(a) Position the search unit to give the maximum amplitude from the reflector. Read and record the *maximum* amplitude in percent of DAC.

(b) Read and record the sweep reading to reflector (at the left side of the indication on the sweep).

(c) Read and record the *position* of the search unit with respect to the reference line.

(d) Read and record the *location* of the indication at the beam center line intersection with reference line from the weld layout reference points.

Move the search unit toward the reflector until the amplitude falls to 60% DAC (half maximum amplitude). Read and record the

(e) *minimum sweep reading* and

(f) *minimum position*

Move the search unit away from the reflector past the maximum amplitude position until the amplitude falls to 60% DAC (half maximum amplitude). Read and record the

(g) *maximum sweep reading* and

(h) *maximum position*

Data points (a) through (h) above shall be read and recorded during the examination. Computations for (i) depth, (j) distance from surface, and length of the

reflector shall be made prior to completion of the examination report.

Subtract the minimum sweep reading from the maximum sweep reading and divide by the sweep reading for one wall thickness and multiply by 100 and record as

(i) *depth* in % of t (t = weld thickness)

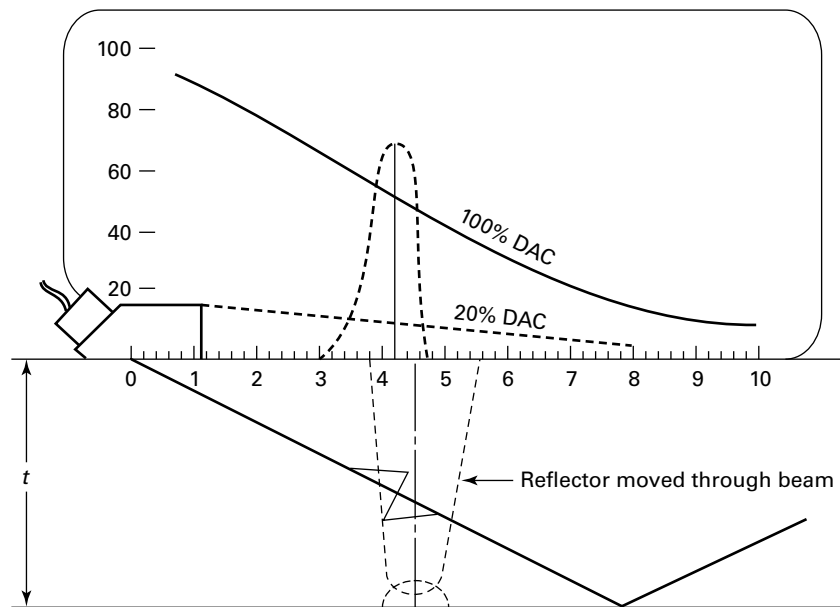
Subtract the maximum sweep reading from the sweep reading for one wall thickness or use the minimum sweep reading, whichever gives the smaller number, and divide the number by the sweep reading for one wall thickness. Multiply by 100 and record as

(j) *distance* from surface in % of t and length of reflection.

Successively read and record data along scan paths at increments no greater than nine-tenths of the transducer (measured parallel to the scan increment change) at 60% DAC (half maximum amplitude). Continue scans until the maximum amplitude found at the end points of the reflector is 20% DAC. The length of the reflector is the distance between the end points measured at the reflector in inches. The length shall be divided by t and multiplied by 100 to give length in % of t . The data tabulated in Fig. D-10 is carried out on either side of the maximum indicated signal until the 20% DAC point is reached on both ends of the indication. It is only necessary to record the data to obtain the

Fig. D-10

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GENERAL NOTE: As the reflector is moved through the beam, the flaw indication reaches 20% DAC at 4.4 sweep divisions, increases in amplitude to 120% DAC at 4.0 sweep divisions, and falls to 20% DAC at 3.6 sweep divisions. The 20% DAC change in sweep reading, divided by the thickness sweep reading, times 100 represents the reflector depth (that is, 10% of t) or the 2 (a) dimension of the subsurface flaw indication.

FIG. D-10 REFLECTOR READING

DATA TABULATION FOR FIG. D-10

(a) Maximum % DAC	(b) Sweep Reading	(c) Search Unit Position, in. or mm	(d) Location, in. or mm	(e) (f) (g) (h) 20% DAC		(i) (j) % of t		Computation or Remarks		
				Minimum		Maximum			Depth	Distance From Surface
				Sweep Reading	Position	Sweep Reading	Position			
120	4.0	4.6	23	3.6	4.2	4.4	5.2	10	45	$\frac{4.4-3.6}{8.0}$
80	4.0	4.6	22.1	3.8	4.3	4.2	4.8	5	47.5	$\frac{4.2-3.8}{8.0}$
20	4.0	4.6	21.7	...	...	...	...	0	50	...
90	4.1	4.7	23.9	3.7	4.3	4.3	5.2	7.5	46	$\frac{4.3-3.7}{8.0}$
70	4.1	4.7	24.8	3.9	4.4	4.3	5.2	5	46	$\frac{4.3-3.9}{8.0}$
20	4.2	4.6	25	...	...	...	...	0	50	...
										depth: 10% of t
										length: 3.3 in. or mm

GENERAL NOTE:
Column letters refer to D-10 subparagraphs.

length 3.3 in. (84 mm) and depth, 10% of t . The first, third, and sixth lines of the data tabulation are all that are necessary to define the through wall and length of the indication in this example.

APPENDIX E — COMPUTERIZED IMAGING TECHNIQUES

E-10 GENERAL REQUIREMENTS

Computerized imaging techniques (CITs) shall satisfy all of the basic instrument requirements described in T-431 and T-461. The search units used for CIT applications shall be characterized as specified in T-434. CITs shall be qualified in accordance with the requirements for flaw detection and/or sizing that are specified in the referencing Code Section.

The written procedure for CIT applications shall identify the specific test frequency and bandwidth to be utilized. In addition, such procedures shall define the signal processing techniques, shall include explicit guidelines for image interpretation, and shall identify the software code/program version to be used. This information shall also be included in the examination report. Each examination report shall document the specific scanning and imaging processes that were used so that these functions may be accurately repeated at a later time if necessary.

The computerized imaging process shall include a feature that generates a dimensional scale (in either two or three dimensions, as appropriate) to assist the operator in relating the imaged features to the actual, relevant dimensions of the component being examined. In addition, automated scaling factor indicators shall be integrally included to relate colors and/or image intensity to the relevant variable (i.e., signal amplitude, attenuation, etc.).

E-20 CALIBRATION

Calibration of computer imaging systems shall be conducted in such a manner that the gain levels are optimized for data acquisition and imaging purposes. The traditional DAC-based calibration process may also be required to establish specific scanning and/or flaw detection sensitivity levels.

For those CITs that employ signal processing to achieve image enhancement (SAFT-UT, L-SAFT, and broadband holography), at least one special lateral resolution and depth discrimination block for each specified examination shall be used in addition to the

applicable calibration block required by Article 4. These blocks shall comply with J-10.

The block described in Fig. E-10 provides an effective resolution range for 45 deg. and 60 deg. search units and metal paths up to about 4 in. (102 mm). This is adequate for piping and similar components, but longer path lengths are required for reactor pressure vessels. A thicker block with the same sizes of flat-bottom holes, spacings, depths, and tolerances is required for metal paths greater than 4 in. (102 mm), and a 4 in. (102 mm) minimum distance between the edge of the holes and the edge of the block is required. These blocks provide a means for determining lateral resolution and depth discrimination of an ultrasonic imaging system.

Lateral resolution is defined as the minimum spacing between holes that can be resolved by the system. The holes are spaced such that the maximum separation between adjacent edges of successive holes is 1.000 in. (25.400 mm). The spacing progressively decreases by a factor of two between successive pairs of holes, and the minimum spacing is 0.015 in. (0.381 mm). Depth discrimination is demonstrated by observing the displayed metal paths (or the depths) of the various holes. Because the hole faces are not parallel to the scanning surface, each hole displays a range [about 0.1 in. (2.54 mm)] of metal paths. The "A" row has the shortest average metal path, the "C" row has the longest average metal path, and the "B" holes vary in average metal path.

Additional blocks are required to verify lateral resolution and depth discrimination when 0 deg. longitudinal-wave examination is performed. Metal path lengths of 2 in. and 8 in. (51 mm and 203 mm), as appropriate, shall be provided as shown in Fig. E-20 for section thicknesses to 4 in. (102 mm), and a similar block with 8 in. (203 mm) metal paths is needed for section thicknesses over 4 in. (102 mm).

E-30 SYNTHETIC APERTURE FOCUSING TECHNIQUE FOR ULTRASONIC TESTING (SAFT-UT)

The Synthetic Aperture Focusing Technique (SAFT) refers to a process in which the focal properties of a large-aperture focused search unit are synthetically generated from data collected while scanning over a large area using a small search unit with a divergent sound beam. The processing required to focus this collection of data is a three-dimensional process called beam-forming, coherent summation, or synthetic aperture processing. The SAFT-UT process offers an inherent

advantage over physical focusing processes because the resulting image is a full-volume, focused characterization of the material volume being examined. Traditional physical focusing processes provide focused data over only the depth of the focus zone of the transducer.

For the typical pulse-echo data collection scheme used with SAFT-UT, a focused search unit is positioned with the focal point located at the surface of the material under examination. This configuration produces a divergent ultrasonic beam in the material. Alternatively, a small-diameter contact search unit may be used to generate a divergent beam. As the search unit is scanned over the surface of the material, the A-scan record (RF waveform) is digitized for each position of the search unit. Any reflector present produces a collection of echoes in the A-scan records. For an elementary single-point reflector, the collection of echoes will form a hyperbolic surface within the data-set volume. The shape of the hyperboloid is determined by the depth of the reflector and the velocity of sound in the material. The relationship between echo location in the series of A-scans and the actual location of reflectors within the material makes it possible to reconstruct a high-resolution image that has a high signal-to-noise ratio. Two separate SAFT-UT configurations are possible: (a) the single-transducer, pulse-echo configuration; and (b) the dual-transducer, tandem configuration (TSAFT).

In general, the detected flaws may be categorized as volumetric, planar, or cracks. Flaw sizing is normally performed by measuring the vertical extent (cracks) or the cross-sectional distance (volumetric/planar) at the -6 dB levels once the flaw has been isolated and the image normalized to the maximum value of the flaw. Multiple images are often required to adequately categorize (classify) the flaw and to characterize the actual flaw shape and size. Tandem sizing and analysis uses similar techniques to pulse-echo, but provides images that may be easier to interpret.

The location of indications within the image space is influenced by material thickness, velocity, and refracted angle of the UT beam. The SAFT algorithm assumes isotropic and homogeneous material; i.e., the SAFT algorithm requires (for optimum performance) that the acoustic velocity be accurately known and constant throughout the material volume.

Lateral resolution is the ability of the SAFT-UT system to distinguish between two objects in an xy plane that is perpendicular to the axis of the sound beam. Lateral resolution is measured by determining the minimum spacing between pairs of holes that are clearly separated in the image. A pair of holes is considered separated if the signal amplitude in the

image decreases by at least 6 dB between the peak signals of two holes.

Depth resolution is the ability of a SAFT-UT system to distinguish between the depth of two holes whose axes are parallel to the major axis of the sound beam. Depth resolution is measured by determining the minimum difference in depth between two holes.

The lateral resolution for a SAFT-UT system is typically 1.5 wavelengths (or better) for examination of wrought ferritic components, and 2.0 wavelengths (or better) for examination of wrought stainless steel components. The depth resolution for these same materials will typically be 0.25 wavelengths (or better).

E-40 LINE-SYNTHETIC APERTURE FOCUSING TECHNIQUE (L-SAFT)

The Line Synthetic Aperture Focusing Technique (L-SAFT) is useful for analyzing detected indications. L-SAFT is a two-dimensional process in which the focal properties of a large-aperture, linearly focused search unit are synthetically generated from data collected over a scan line using a small search unit with a diverging sound beam. The processing required to impose a focusing effect of the acquired data is also called synthetic aperture processing. The L-SAFT system can be operated like conventional UT equipment for data recording. It will function with either single- or dual-element transducers.

Analysis measurements, in general, are performed to determine flaw size, volume, location, and configuration. To decide if the flaw is a crack or volumetric, the crack-tip-diffraction response offers one criterion, and the superimposed image of two measurements made using different directions of incidence offers another.

All constraints for SAFT-UT apply to L-SAFT and vice versa. The difference between L-SAFT and SAFT-UT is that SAFT-UT provides a higher resolution image than can be obtained with L-SAFT.

E-50 BROADBAND HOLOGRAPHY TECHNIQUE

The holography technique produces an object image by calculation based on data from a diffraction pattern. If the result is a two-dimensional image and the data are acquired along one scan, the process is called "line-holography." If the result is a two-dimensional image based upon an area scanned, then it is called "holography." For the special case of applying holography principles to ultrasonic testing, the image of flaws (in more than one dimension) can be obtained by recording

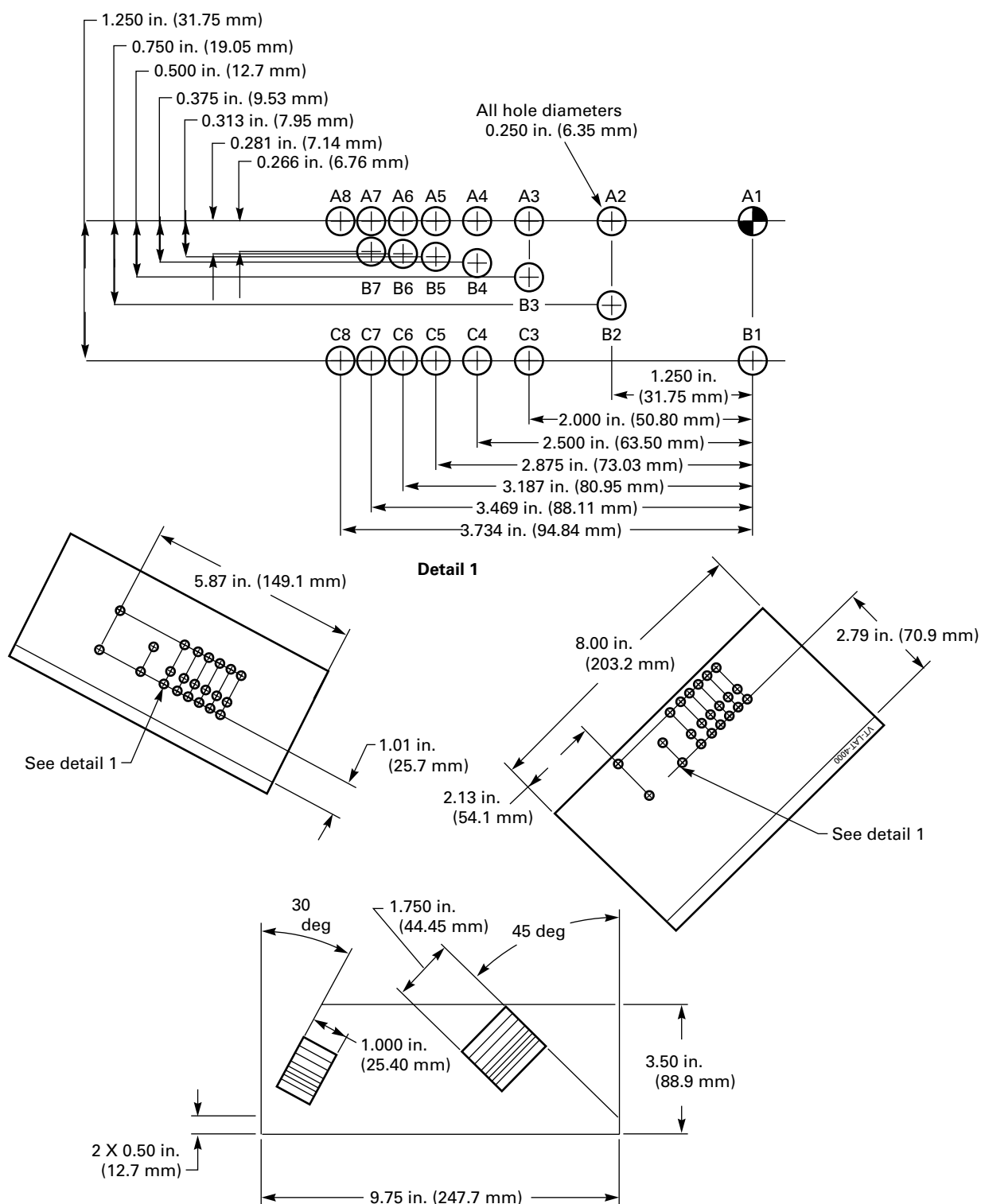


FIG. E-10 LATERAL RESOLUTION AND DEPTH DISCRIMINATION
BLOCK FOR 45 deg. AND 60 deg. APPLICATIONS
(Not to Scale)

GENERAL NOTES:

- (a) View rotated for clarity.
- (b) Insonification surface is shown at bottom.
- (c) Tolerances: decimals: 0.XX = ± 0.03 ; 0.XXX = ± 0.005 ; angular: ± 1 deg.
- (d) Hole identification:
 - (1) Engrave or stamp as shown with the characters upright when the large face of the block is up.
 - (2) Nominal character height is 0.25 in. (6.4 mm)
 - (3) Start numbering at the widest-spaced side.
 - (4) Label row of eight holes A1–A8.
 - (5) Label diagonal set of seven holes B1–B7.
 - (6) Label remaining six holes C3–C8.
- (e) Hole spacing: minimum 0.010 in. (0.25 mm) material between hole edges.
- (f) Hole depths: 30 deg. face: 1.000 in. (25.40 mm); 45 deg. face: 1.750 in.
- (g) Drawing presentation: holes are shown from drilled face of block.
- (h) Hole ends to be flat and parallel to drilled surface within 0.001 in. (0.03 mm) across face of hole.
- (i) Maximum radius between side and face of hole is 0.005 in. (0.13 mm)

FIG. E-10 LATERAL RESOLUTION AND DEPTH DISCRIMINATION
BLOCK FOR 45 deg. AND 60 deg. APPLICATIONS (CONT'D)

the amplitude, phase, and time-of-flight data from the scanned volume. The holography process offers a unique feature because the resulting image is a one- or two-dimensional characterization of the material.

This technique provides good resolution in the axial direction by using broadband search units. These search units transmit a very short pulse, and therefore the axial resolution is improved. The maximum bandwidth may be 20 MHz without using filtering, and up to 8 MHz using an integrated filter.

Analysis measurements, in general, are performed to obtain information on size, volume, location, and configuration of detected flaws. The results of the holography-measurements per scan line show a two-dimensional image of the flaw by color-coded display. The size of flaws can be determined by using the 6 dB drop in the color code. More information on the flaw dimensions is obtained by scans in different directions (i.e., parallel, perpendicular) at different angles of incidence. To decide if the flaw is a crack or a volumetric flaw, the crack tip technique offers one criterion and comparison of two measurements from different directions of incidence offers another. Measurement results obtained by imaging techniques always require specific interpretation. Small variations in material thickness, sound velocity, or refracted beam angle may influence the reconstruction results. The holography processing calculations also assume that the velocity is accurately known and constant throughout the material.

E-60 UT-PHASED ARRAY TECHNIQUE

The UT-Phased Array Technique is a process wherein UT data are generated by controlled incremental varia-

tion of the ultrasonic beam angle in the azimuthal or lateral direction while scanning the object under examination. This process offers an advantage over processes using conventional probes with fixed beam angles because it acquires considerably more information about the reflecting object by using more aspect angles in direct impingement.

Each phased array probe consists of a series of individually wired transducer elements on a wedge that are activated separately using a pre-selectable time delay pattern. With a linear delay time between the transmitter pulses, an inclined sound field is generated. Varying the angle of refraction requires a variation of the linear distribution of the delay time. Depending on the probe design, it is possible to electronically vary either the angle of incidence or the lateral/skew angle. In the receiving mode, acoustic energy is received by the elements and the signals undergo a summation process utilizing the same time delay pattern as was used during transmission.

Flaw sizing is normally performed by measuring the vertical extent (in the case of cracks) or the cross-sectional distance (in the case of volumetric/planar flaws) at the 6 dB levels once the flaw has been isolated and the image normalized. Tandem sizing and analysis uses techniques similar to pulse-echo but provides images that are easier to interpret since specular reflection is used for defects oriented perpendicular to the surface. For cracks and planar defects, the result should be verified using crack-tip-diffraction signals from the upper and lower ends of the flaw, since the phased array approach with tomographic reconstruction is most sensitive to flaw tip indications and is able to give a clear reconstruction image of these refraction

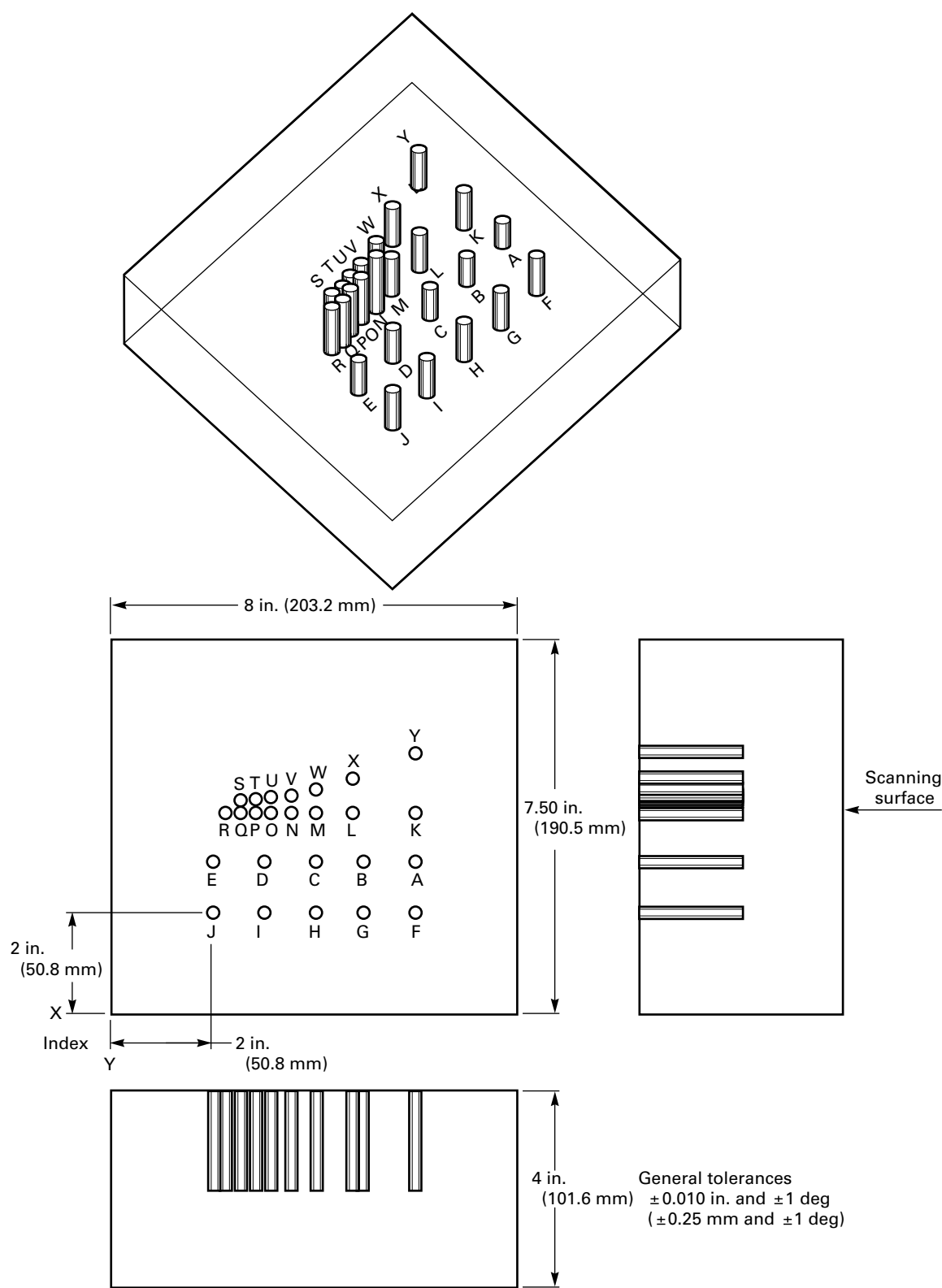


FIG. E-20 LATERAL AND DEPTH RESOLUTION BLOCK FOR 0 deg. APPLICATIONS

TABLE E-20
HOLE PATTERN DIMENSIONS
FOR CALIBRATION BLOCK

	Hole Position		Hole Depth, ±0.002 in. (±0.05 mm)
	X, ±0.005 in. (±0.13 mm)	Y, ±0.005 in. (±0.13 mm)	
A	6.000 (152.40)	3.000 (76.20)	1.080 (27.43)
B	5.000 (127.00)	3.000 (76.20)	1.310 (33.27)
C	4.000 (101.60)	3.000 (76.20)	1.540 (39.12)
D	3.000 (76.20)	3.000 (76.20)	1.770 (44.96)
E	2.000 (50.80)	3.000 (76.20)	2.000 (50.80)
F	6.000 (152.40)	2.000 (50.80)	1.828 (46.43)
G	5.000 (127.00)	2.000 (50.80)	1.885 (47.88)
H	4.000 (101.60)	2.000 (50.80)	1.943 (49.35)
I	3.000 (76.20)	2.000 (50.80)	1.977 (50.22)
J	2.000 (50.80)	2.000 (50.80)	2.000 (50.80)

	Hole Position		Hole Depth, ±0.005 in. (±0.13 mm)
	X, ±0.002 in. (±0.05 mm)	Y, ±0.002 in. (±0.05 mm)	
K	6.000 (152.40)	4.000 (101.60)	2.000 (50.80)
L	4.750 (120.65)	4.000 (101.60)	2.000 (50.80)
M	4.000 (101.60)	4.000 (101.60)	2.000 (50.80)
N	3.500 (88.90)	4.000 (101.60)	2.000 (50.80)
O	3.125 (79.38)	4.000 (101.60)	2.000 (50.80)
P	2.813 (71.45)	4.000 (101.60)	2.000 (50.80)
Q	2.532 (64.31)	4.000 (101.60)	2.000 (50.80)
R	2.266 (57.56)	4.000 (101.60)	2.000 (50.80)
S	2.532 (64.31)	4.266 (108.36)	2.000 (50.80)
T	2.813 (71.45)	4.281 (108.74)	2.000 (50.80)
U	3.125 (79.38)	4.322 (109.78)	2.000 (50.80)
V	3.500 (88.90)	4.375 (111.13)	2.000 (50.80)
W	4.000 (101.60)	4.500 (114.30)	2.000 (50.80)
X	4.750 (120.65)	4.750 (120.65)	2.000 (50.80)
Y	6.000 (152.40)	5.250 (133.35)	2.000 (50.80)

GENERAL NOTE: Drill all holes flat-bottomed and perpendicular to the scanning surface. Hole diameters shall be 0.250 ± 0.005 in. (6.35 ± 0.13 mm) in Faces #1 and #2, and 0.250 ± 0.002 in. (6.35 ± 0.05 mm) in Faces #3 and #4. Hole bottoms shall be parallel to the scanning surface to within 1 deg. Maximum radius of hole bottom corners shall be 0.010 in. (0.25 mm).

phenomena. As with other techniques, the phased array process assumes isotropic and homogeneous material whose acoustic velocity is constant and accurately known.

E-70 UT-AMPLITUDE TIME-OF-FLIGHT LOCUS-CURVE ANALYSIS TECHNIQUE

The UT-amplitude time-of-flight locus-curve analysis technique utilizes multiple probes in pulse-echo, trans-

mitter-receiver, or tandem configuration. Individually selectable parameters control the compression of the A-scan information using a pattern-recognition algorithm, so that only the relevant A-scan amplitudes are stored and further processed.

The parameter values in the A-scan compression algorithm determine how many pre-cursing and how many post-cursing half-wave peaks must be smaller than a specific amplitude, so that this largest amplitude is identified as a relevant signal. These raw data can be displayed in B-, C-, and D-scan (side, top, and end view) presentations, with selectable color-code increments for amplitude and fast zoom capabilities. This operating mode is most suitable for detection purposes. For discrimination, a two-dimensional spatial-filtering algorithm is applied to search for correlation of the time-of-flight raw data with reflector-typical time-of-flight trajectories.

Tandem sizing and analysis uses techniques similar to pulse-echo but provides images that may be easier to interpret since the specular reflections from flaws oriented perpendicular to the surface are used. For cracks and planar flaws, the results should be verified with crack-tip-diffraction signals from the upper and lower end of the flaw since the acoustic parameters are very sensitive to flaw tip indications and a clear reconstruction image of these refraction phenomena is possible with this technique.

The location of indications within the image space is influenced by material thickness and actual sound velocity (i.e., isotropic and homogeneous material is assumed). However, deteriorating influences from anisotropic material (such as cladding) can be reduced by appropriate selection of the search unit parameters.

E-80 AUTOMATED DATA ACQUISITION AND IMAGING TECHNIQUE

Automated data acquisition and imaging is a multi-channel technique that may be used for acquisition and analysis of UT data for both contact and immersion applications. This technique allows interfacing between the calibration, acquisition, and analysis modes; and for assignment of specific examination configurations. This technique utilizes a real-time display for monitoring the quality of data being collected, and provides for display of specific amplitude ranges and the capability to analyze peak data through target motion filtering. A cursor function allows scanning the RF data one waveform at a time to aid in crack sizing using tip-diffraction. For both peak and RF data, the technique

can collect, display, and analyze data for scanning in either the axial or circumferential directions.

This technique facilitates detection and sizing of both volumetric and planar flaws. For sizing volumetric flaws, amplitude-based methods may be used; and for sizing planar flaws, the crack-tip-diffraction method may be used. An overlay feature allows the analyst to generate a composite image using several sets of ultrasonic data. All data displayed in the analyze mode may be displayed with respect to the physical coordinates of the component.

APPENDIX F — NOZZLE EXAMINATION

F-10 GENERAL REQUIREMENTS

This Appendix provides rules for equipment and procedure qualification and/or requalification of manual or automated ultrasonic examinations of the nozzle inside radius. The Manufacturer, examination agency, or other user of this Appendix shall be responsible for qualifying the technique, equipment, and written procedure(s) in conformance with this Appendix, and/or as required by the referencing Code Section.

F-20 PERFORMANCE DEMONSTRATION FOR NOZZLE INSIDE RADIUS EXAMS

The equipment and procedure performance demonstration requirements specified in this Appendix may be satisfied simultaneously or in conjunction with other qualification(s)/verification and/or requalification demonstration in conformance with this Appendix.

(a) Ultrasonic instruments shall comply with the Instrument Requirements of F-30.

(b) Specimens to be employed during calibration and/or qualification test shall comply with the requirements of F-40.

(c) The equipment and procedure shall be considered qualified for detection of flaws upon successfully completing the performance demonstration specified in F-60, Procedure Qualification.

F-21 Personnel Requirements

Personnel shall be qualified and certified in accordance with the requirements of the referencing Code.

F-30 INSTRUMENT REQUIREMENTS

(a) A pulse-echo type of ultrasonic instrument and/or examination system shall be used. The instrument/system shall be equipped with a stepped gain control calibrated in units of 2.0 dB or less.

(b) The system shall exhibit the following:

(1) Center Frequency:

(a) For examination systems with bandwidths less than 30%, the center frequency shall not change more than $\pm 5\%$.

(b) For examination systems with bandwidths 30% or greater, the system center frequency shall not vary more than $\pm 10\%$.

(2) Bandwidth:

(a) The examination bandwidth shall not change more than $\pm 10\%$.

NOTE: Bandwidth is measured at the -6 dB points.

F-31 Procedure Requirements

F-31.1 Written Procedure. Ultrasonic nozzle inside radius examination shall be performed in accordance with a written procedure. The procedure shall be qualified to the extent specified in this Subsection. The examination procedure shall contain a statement of scope that specifically defines the limits of procedure applicability. The examination procedure shall specify a single value or a range of values for the listed essential variables. The examination procedure shall specify, as a minimum, the following essential variables:

(a) instrument or system description including Manufacturer and model of pulser, receiver, and amplifier;

(b) ultrasonic technique;

(c) search units, including:

(1) number, size, shape, and configuration of active elements

(2) center frequency and either bandwidth or waveform for each active element

(3) mode of sound propagation; e.g., longitudinal, shear, etc.

(d) scanning equipment (when applicable);

(1) type; manipulator(s), bridges, semi-automatic devices

(2) indexing controls, scanners

(3) number of ultrasonic connectors; and length of cable

(e) scanning technique(s), including:

(1) scan pattern (modeling) and primary beam direction

(2) maximum scan speed

- (3) minimum and maximum pulse repetition rate
- (4) minimum sampling rate (automatic recording systems)
- (5) extent of scanning and action to be taken for geometrical restrictions.
- (f) methods of calibration for detection. Calibration methods include all those actions required to assure that the accuracy of the signal amplitude and sweep locations of the examination system (whether displayed, recorded, or automatically processed) are repeatable from examination to examination. Any method of achieving the system calibration shall be recorded. A description of the calibrated sensitivity shall be included in the procedure.
- (g) minimum inspection/calibration data to be recorded, and medium, i.e., calibration sheet and/or magnetic disk;
- (h) method of data recording, and recording equipment (strip chart, analog tape, digitizing);
- (i) method and criteria for the discrimination of indications (e.g., geometric versus flaw), and for depth of flaws;
- (j) surface condition requirements, scanner's mounting requirements;
- (k) identification of qualification specimen, overall configuration; material, product form, shell thickness, bore barrel thickness and diameter(s);
- (l) essential variable range(s).

F-31.2 Essential Variable Requalification. When the essential variables exceed the tolerances specified within the qualification procedure, the qualification test shall be repeated in conformance with F-60.

F-40 QUALIFICATION SPECIMEN

- (a) The qualification process shall be conducted using a full-scale or partial section nozzle (mockup), which is dimensionally sufficient to contain the maximum beam path, examination volume, and the necessary reflectors that are to be detected.
- (b) If the examining beams pass only through the nozzle forging, the mockup may be a nozzle forging, or segment of a forging, which may be fixed in a structure to simulate adjacent vessel surfaces as required for examination alignment. If the examining beams pass through the nozzle to shell weld, the mockup shall contain nozzle weld and shell components of sufficient size to permit qualification.
- (c) The qualification specimen shall meet the requirements of the vessel specification(s) with respect to:

(1) the basic calibration block material requirements (J-10).

(2) *Curvature.* The examination and reflection surface curvatures on the nozzle mockup shall be similar to those curvatures on the nozzle in the vessel. The size ranges in F-40(c)(6) below shall be considered to be similar curvatures.

(3) welding process (when applicable).

(4) *Cladding.* If the inside surface of the nozzle in the vessel is clad, the inside surface of the nozzle mockup shall be clad using the same welding method (i.e., roll bonded, manual weld deposited, automatic wire deposited, or automatic strip deposited). In the event the cladding method is not known or is impractical to apply on the mockup, cladding may be applied using the manual weld deposit method. If the inside surface of the nozzle to be examined is not clad, the inside surface of the nozzle mockup may be cladded, as long as the reflectors are contained within the base metal interface to the required volume.

NOTE: Vessel cladding direction, where known, should be simulated.

(5) *Thickness.* Calibration specimen and/or mockup shall equal or exceed the maximum component thickness in the region to be qualified.

(6) *Ratio limits for curved surfaces.* Mockup diameter range in the area of qualification shall be determined by Fig. J-10. For diameters greater than 4 in. (102 mm), mockup curvature shall be in the range of 0.9 to 1.5 times the nozzle under examination.

F-50 QUALIFICATION SPECIMEN REFLECTORS

The qualification specimen shall contain a minimum of three reflectors within the examination volume for detection qualification. Optionally, induced or embedded cracks may be used in lieu of machined reflectors. Additionally these reflectors may be employed for demonstration of the procedure's sizing capabilities, when required by the referencing Code.

F-51 Reflectors

The qualification reflectors shall be distributed within the examination volume and shall meet the following requirements.

(a) Reflectors shall be distributed radially in two zones with at least one reflector in each zone. Zone 1 ranges between 0 deg. and 180 deg. (± 45 deg.), Zone 2 is the remaining two quadrants, centered on the nozzle's horizontal axis.

(b) Machined reflectors shall be placed within the nozzle inner radii examination volume and specified to be oriented parallel to the axial radial plane of the nozzle within a manufacturing tolerance of ± 2 deg.

(c) Machined reflectors shall be specified to be oriented perpendicular to the ID surface of the nozzle within a manufacturing tolerance of ± 2 deg.

(d) Reflectors shall have a maximum length of 1.0 in. (25 mm), and a nominal width of 0.0625 in. (1.59 mm) ($\pm 10\%$).

(e) Machined reflectors shall have depth ranges, measured from the inside surface of the base material.

(1) Reflector No. 1 — 0.201–0.350

(2) Reflector No. 2 — 0.351–0.550

(3) Reflector No. 3 — 0.551–0.750

Induced crack reflectors are permitted, provided they are located in conformance with F-51(a) and (b) and their depths are within the range of reflectors in F-51(e).

F-60 PROCEDURE QUALIFICATION

The procedure shall be considered qualified for detection when all qualifying reflectors are located within 1.5 in. (38 mm) of their true position (x and y). Sizing qualification, when required, shall be in accordance with referencing Code requirements.

F-61 Requalification

The procedure shall require requalification when an essential variable of the qualified procedure has been changed and/or exceeded.

F-70 CALIBRATION

Calibration is defined as all of the processes necessary to configure the examination system prior to the examination that must be performed in order to satisfactorily qualify the equipment and procedure. Instrument calibration settings used during procedure qualification shall be repeated during subsequent field exams. Calibration simulators may be employed for field instrument calibration provided they can be correlated with the original calibration on the basic calibration block (if used) during the original calibration.

F-71 Calibration Checks

If used, subsequent calibration checks may be performed on either the qualification specimen, mockup, and/or simulator calibration block(s).

APPENDIX G

(In the Course of Preparation.)

APPENDIX H — RECORDING ANGLE BEAM EXAMINATION DATA FOR PLANAR REFLECTORS

H-10 RECORDING DATA

This Appendix describes a method for recording angle beam examination data for planar reflectors when amplitude based dimensioning is to be performed.

(a) Record all reflectors that produce a response equal to or greater than 20% of the distance-amplitude correction (DAC). However, the clad interface metallurgical reflectors and back wall reflections need not be recorded. Record surface reflectors that produce a response equal to or exceeding the calibration amplitude established per B-7(d). Record all search unit position and location dimensions to the nearest tenth of an inch.

(b) Obtain data from successive scans at increments no greater than nine-tenths of the transducer dimension measured parallel to the scan increment change (10% overlap). Record data for the end points as determined by 20% of DAC. Emphasis must be placed on measurement of the parameters determining the reflector length and height and the distances from the examination surface to the top and bottom of the reflector, since these dimensions are the factors most critical in determining ultimate evaluation and disposition of the flaw (see Appendix D for an illustrated example).

(c) The following reflector data shall be recorded when a reflector exceeds 20% DAC.

(1) Maximum percent of DAC, sweep reading of indication, search unit position, location along the length of the weld, and beam direction.

(2) *Through-Wall Dimension*

(a) For reflectors 20% to 100% DAC, the minimum sweep reading and its position and location along the length of the reflector for 20% DAC when approaching the reflector from the maximum signal direction.

(b) For reflectors 20% to 100% DAC, the maximum sweep reading and its position and location along the length of the reflector for 20% DAC when moving away from the reflector's maximum signal direction.

(c) For reflectors exceeding 100% DAC, minimum sweep reading and its position and location along the length of the reflector for 50% of the maximum amplitude when approaching the reflector from the maximum signal direction.

(d) For reflectors exceeding 100% DAC, maximum sweep reading and its position and location along the length of the reflector for 50% of the maximum amplitude when moving away from the reflector's maximum signal direction.

(3) *Length Dimension.* The length of the reflector shall be obtained by recording the position and location along the length of weld as determined by 20% of DAC for each end of the reflector.

APPENDIX I — EXAMINATION OF WELDS USING ANGLE BEAM SEARCH UNITS

I-10 EXAMINATION OF WELDS

This Appendix describes a method of examination of welds using angle beam search units.

I-20 GENERAL SCANNING REQUIREMENTS

Three angle beams, having nominal angles of 45 deg., 60 deg., and 70 deg. with respect to a perpendicular to the examination surface, shall generally be used. Beam angles other than 45 deg. and 60 deg. are permitted provided the measured difference between angles is at least 10 deg. Additional $\frac{1}{4}$ volume angle beam examination shall be conducted on the material volume within $\frac{1}{4}$ of the thickness adjacent to the examination surface. Single or dual element longitudinal or shear wave angle beams in the range of 60 deg. through 70 deg. with respect to perpendicular to the examination surface shall be used in this $\frac{1}{4}$ volume.

I-30 EXCEPTIONS TO GENERAL SCANNING REQUIREMENTS

Other angles may be used for examination of:

- (a) flange welds, when the examination is conducted from the flange face;
- (b) nozzles and nozzle welds, when the examination is conducted from the nozzle bore;
- (c) attachment and support welds;
- (d) examination of double taper junctures.

APPENDIX J — BASIC CALIBRATION BLOCK

This Appendix contains the description for a basic calibration block used for distance-amplitude correction (DAC) calibration techniques.

The basic calibration block(s) containing basic calibration reflectors to establish a primary reference response of the equipment and to construct a distance-amplitude correction curve shall be as shown in Fig. J-10. The basic calibration reflectors shall be located either in the component material or in a basic calibration block.

J-10 BASIC CALIBRATION BLOCK MATERIAL

(a) *Block Selection.* The material from which the block is fabricated shall be from one of the following:

- (1) nozzle dropout from the component;
- (2) a component prolongation;

(3) material of the same material specification, product form, and heat treatment condition as the material to which the search unit is applied during the examination.

(b) *Clad.* Where the component material is clad and the cladding is a factor during examination, the block shall be clad to the component clad nominal thickness $\pm \frac{1}{8}$ in. (3.2 mm). Deposition of clad shall be by the same method (i.e., rollbonded, manual weld deposited, automatic wire deposited, or automatic strip deposited) as used to clad the component to be examined. In the event the cladding method is not known or the method of cladding used on the component is impractical for block cladding, deposition of clad shall be by the manual method. It is desirable to have component materials which have been clad before the drop outs or prolongations are removed. When the parent material on opposite sides of a weld are clad by different methods, the cladding on the calibration block shall be applied by the method used on the side of the weld from which the examination will be conducted. When the examination is conducted from both sides, the calibration block shall provide for calibration for both methods of cladding.

(c) *Heat Treatment.* The calibration block shall receive at least the minimum tempering treatment required by the material specification for the type and grade and a postweld heat treatment of at least 2 hr.

(d) *Surface Finish.* The finish on the surfaces of the block shall be representative of the surface finishes of the component.

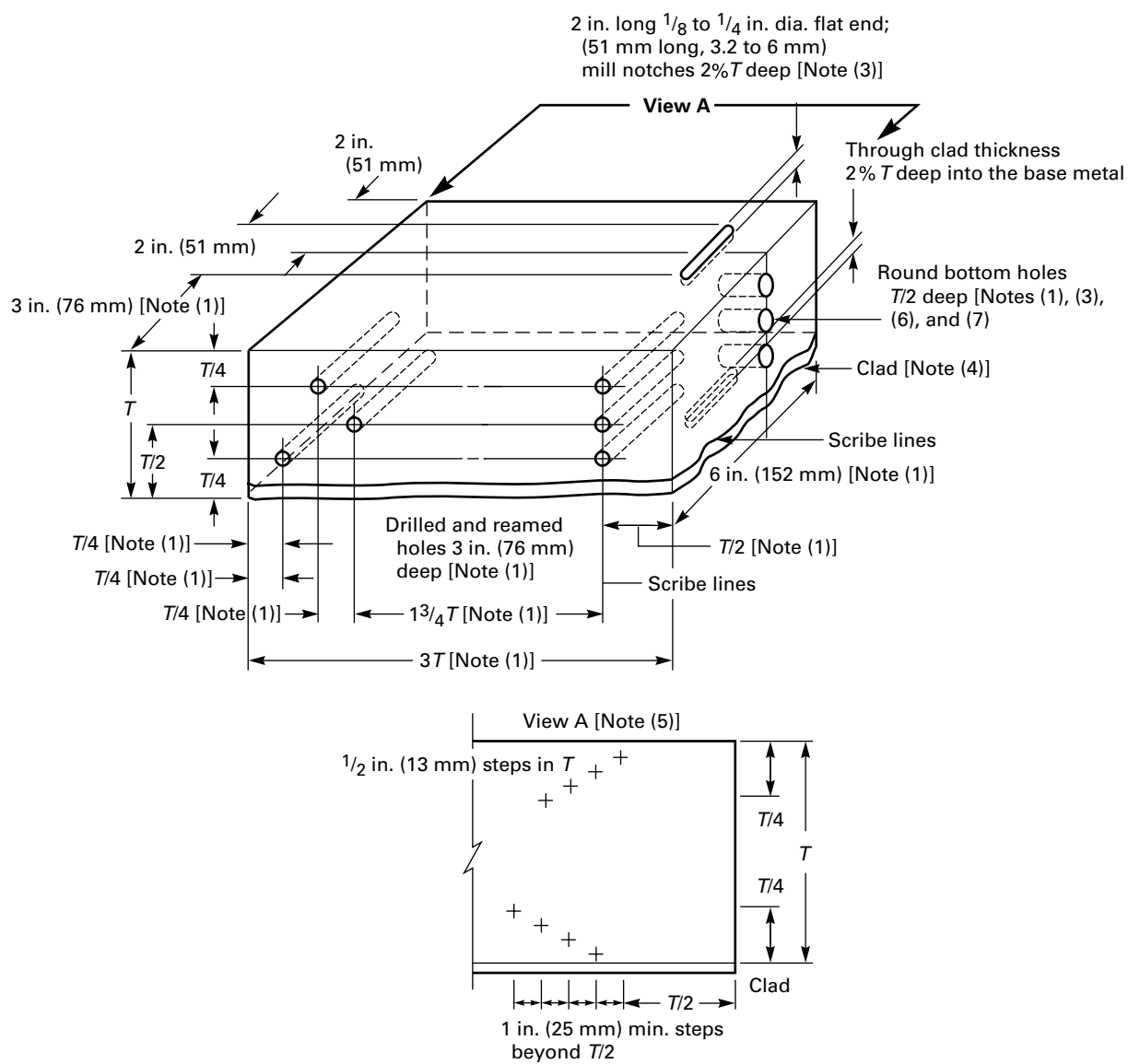


FIG. J-10 BASIC CALIBRATION BLOCK

Weld Thickness t , in. (mm)	Basic Calibration Block Thickness T , in. (mm)	Side Drilled Hole Diameter, in. (mm) [Note (3)]	Round Bottom Hole Diameter, in. (mm) [Notes (3) and (6)]
Over 2 through 4 (51 through 102)	3 or t (76 or t)	$\frac{3}{16}$ (4.8)	$\frac{3}{8}$ (9.5)
Over 4 through 6 (102 through 152)	5 or t (127 or t)	$\frac{1}{4}$ (6.4)	$\frac{7}{16}$ (11.1)
Over 6 through 8 (152 through 203)	7 or t (178 or t)	$\frac{5}{16}$ (7.9)	$\frac{1}{2}$ (12.7)
Over 8 through 10 (203 through 254)	9 or t (230 or t)	$\frac{3}{8}$ (9.5)	$\frac{9}{16}$ (14.3)
Over 10 through 12 (254 through 305)	11 or t (280 or t)	$\frac{7}{16}$ (11.1)	$\frac{5}{8}$ (15.9)
Over 12 through 14 (305 through 356)	13 or t (330 or t)	$\frac{1}{2}$ (12.7)	$\frac{11}{16}$ (17.5)
Over 14 (356)	$t \pm 1$ ($t \pm 25$)	[Note (2)]	[Note (2)]

NOTES:

- (1) Minimum dimensions.
- (2) For each increase in weld thickness of 2 in. (50.8 mm) or fraction thereof over 14 in. (356 mm), the hole diameter shall increase $\frac{1}{16}$ in. (1.6 mm).
- (3) The tolerances for the hole diameters shall be $\pm \frac{1}{32}$ in. (0.8 mm); tolerances on notch depth shall be +10 and -20% (need only be held at the thinnest clad thickness along the reflecting surface of the notch); tolerance on hole location through the thickness shall be $\pm \frac{1}{8}$ in. (3.2 mm); perpendicular tolerances on notch reflecting surface shall be ± 2 deg; tolerance on notch length shall be $\pm \frac{1}{4}$ in. (± 6.4 mm).
- (4) Clad shall not be included in T .
- (5) Subsurface calibration holes $\frac{1}{8}$ in. (3.2 mm) (maximum) diameter by $1\frac{1}{2}$ in. (38.1 mm) deep (minimum) shall be drilled at the clad-to-base metal interface and at $\frac{1}{2}$ in. (12.7 mm) increments through $\frac{7}{4}$ from the clad surface, also at $\frac{1}{2}$ in. (12.7 mm) from the unclad surface and at $\frac{1}{2}$ in. (12.7 mm) increments through $\frac{7}{4}$ from the unclad surface. In each case, the hole nearest the surface shall be drilled at $\frac{7}{2}$ from the edge of the block. Holes at $\frac{1}{2}$ in. (12.7 mm) thickness increments from the near surface hole shall be drilled at 1 in. (25.4 mm) minimum intervals from $\frac{7}{2}$.
- (6) Round (hemispherical) bottom holes shall be drilled only when required by a Referencing Code Section for beam spread measurements (see T-434.1) and the technique of B-60 is used. The round bottom holes may be located in the largest block in a set of basic calibration blocks, or in a separate block representing the maximum thickness to be examined.
- (7) $\frac{7}{2}$ hole may be located in the opposite end of the block.

FIG. J-10 BASIC CALIBRATION BLOCK (CONT'D)

(e) *Block Quality.* The calibration block material shall be completely examined with a straight beam search unit. Areas that contain indications exceeding the remaining back reflection shall be excluded from the beam paths required to reach the various calibration reflectors.

J-20 CALIBRATION REFLECTORS

(a) *Basic Calibration Reflectors.* The side of a hole drilled with its axis parallel to the examination surface is the basic calibration reflector. A square notch shall also be used. The reflecting surface of the notches shall be perpendicular to the block surface. See Fig. J-10.

(b) *Scribe Line.* A scribe line as shown in Fig. J-10 shall be made in the thickness direction through the in-line hole center lines and continued across the two examination surfaces of the block.

(c) *Additional Reflectors.* Additional reflectors may be installed; these reflectors shall not interfere with establishing the primary reference.

(d) *Basic Calibration Block Configuration.* Figure J-10 shows block configuration with hole size and location. Each weld thickness on the component must be represented by a block having a thickness relative to the component weld as shown in Fig. J-10. Where the block thickness ± 1 in. (25 mm) spans two of the weld thickness ranges shown in Fig. J-10, the block's use shall be acceptable in those portions of each thickness range covered by 1 in. (25 mm). The holes shall be in accordance with the thickness of the block. Where two or more base material thicknesses are involved, the calibration block thickness shall be sufficient to contain the entire examination beam path.

(e) *Welds in Materials With Diameters Greater Than 20 in. (508 mm).* For examination of welds in materials where the examination surface diameter is greater than 20 in. (508 mm), a single curved basic calibration block may be used to calibrate the straight and angle beam examinations on surfaces in the range of curvature from 0.9 to 1.5 times the basic calibration block diameter. Alternatively, a flat basic calibration block may be used provided the minimum convex, concave, or

compound curvature radius to be examined is greater than the critical radius determined by Article 5 of Appendix A. For the purpose of this determination, the dimension of the straight or angle beam search units flat contact surface tangent to the minimum radius shall be used instead of the transducer diameter in Table A-10.

(f) *Welds in Materials With Diameters 20 in. (508 mm) and Less.* The basic calibration block shall be curved for welds in materials with diameters 20 in. (508 mm) and less. A single curved basic calibration block may be used to calibrate the examination on surfaces in the range of curvature from 0.9 to 1.5 times the basic calibration block diameter. For example, an 8 in. (203 mm) diameter curved block may be used to calibrate the examination on surfaces in the range of curvature from 7.2 in. (183 mm) to 12 in. (305 mm) diameter. The curvature range from 0.94 in. (24 mm) to 20 in. (508 mm) diameter requires six block curvatures as indicated in Fig. J-20 for any thickness range as indicated in Fig. J-10.

(g) *Retention and Control.* All basic calibration blocks for the examination shall meet the retention and control requirements of the referencing Code Section.

APPENDIX K — RECORDING STRAIGHT BEAM EXAMINATION DATA FOR PLANAR REFLECTORS

This Appendix describes a method for recording straight beam examination data for planar reflectors when amplitude based dimensioning is to be performed.

(a) Record all reflectors that produce a response equal to or greater than 50% of the distance-amplitude correction (DAC). However, clad interface and back wall reflections need not be recorded. Record all search unit position and location dimensions to the nearest tenth of an inch.

(b) Obtain data from successive scans at increments no greater than nine-tenths of the transducer dimension measured parallel to the scan increment change (10% overlap). Record data for the end points as determined by 50% of DAC.

APPENDIX L — EXAMINATION OF BOLTS AND STUDS

L-10 GENERAL REQUIREMENTS

This Appendix provides guidance for examining bolts and studs from the end face after threading by the

axial-straight beam technique to locate and evaluate service-induced discontinuities. When the referencing Code Section requires examination per this Appendix, the axial straight beam examinations shall be performed over an entire end surface and the following paragraphs shall apply.

L-11 Written Procedure Requirements

Ultrasonic examination shall be performed in accordance with a written procedure that shall include the following information:

(a) bolt or stud configurations to be examined, including length, diameter, thread size, plating, materials, and product form (e.g., bolt or stud, rolled or cut thread);

(b) scanning surfaces, surface condition requirements, and surface preparation methods;

(c) equipment used, including the following information;

(1) make and model of instrument;

(2) search units type, angle, frequency, and transducer (crystal size);

(3) sizes and configurations of wedges and shoes;

(4) automatic alarm recording equipment;

(5) rotating, revolving, or scanning equipment;

(6) couplant, and

(7) search unit cable type, length, and number of connectors.

(d) examination technique including angles, modes of wave propagation in the material, directions, maximum speed, and extent of scanning;

(e) techniques of calibration and of establishing scanning sensitivity levels, including instrument controls to be used and acceptance standards for the calibrated condition;

(f) identification of calibration blocks;

(g) data to be recorded and method of recording;

(h) detectability limitation and location accuracy;

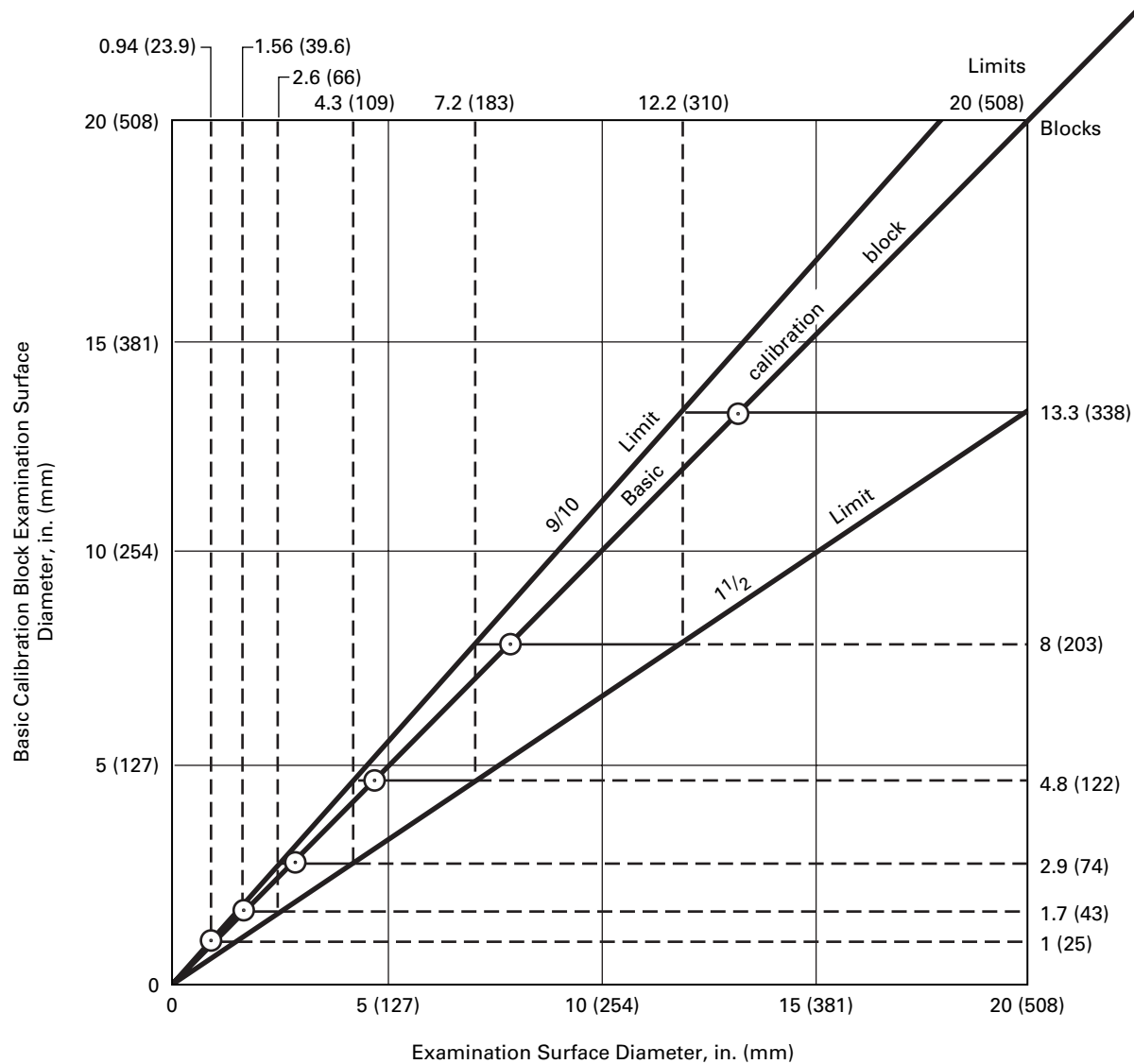
(i) examination volume covered considering loss in coverage from near and far surface resolution limitations;

(j) methods of data interpretation and plotting; and

(k) personnel qualification requirements.

L-12 Search Units

Search units may contain either single or dual elements. Search units with angled contact wedges may be used to aid in ultrasonic coupling. Calibration shall be performed with the contact wedges used during the examination.



GENERAL NOTES:

- Plot examination surface of basic calibration block on diagonal (45 deg) line.
- Draw horizontal line through that point from the 9/10 to the 1 1/2 limit line.
- The ends of this line read on the horizontal scale give the range of examination surface diameters which may be examined with a system calibrated on this block.
- Thickness range requirements shall also be satisfied.

FIG. J-20 RATIO LIMITS FOR CURVED SURFACES

TABLE L-13.1
NOTCH DIMENSIONS

Bolt or Stud Size	Maximum Notch Dimensions			
	Depth ¹ , in. (mm)		Reflective Area ² , sq. in. (mm ²)	
Greater than 4 in. (102 mm) diameter	0.157 (3.99)		0.059 (38.06)	
2 in. (51 mm) diameter and greater, but not over 4 in. (102 mm) diameter	0.107 (2.72)		0.027 (17.42)	

NOTES:

- (1) For threaded surfaces, depth is measured from bottom of thread root to bottom of notch.
 (2) Reflective area shall be no larger than the required area.

L-13 Basic Calibration Block

A system calibration shall be performed using a full-scale or partial section bolt or stud which is sufficient to contain the sound beam path and the area of interest, and to demonstrate the scanning technique.

(a) The basic calibration block shall be of the same material specification, product form, and surface finish as the bolt or stud to be examined.

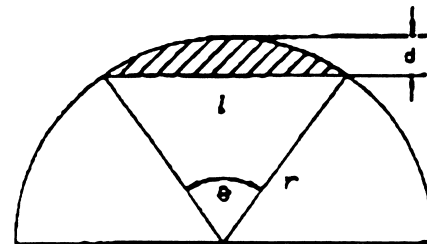
(b) Reflectors shall be notches with a depth and area as specified in Table L-13.1 at the minimum end and maximum metal paths except that notches need not be located closer than one diameter from either end.

If these notches are in the threaded section, they shall be machined from the base of the thread root and shall follow the beam angle of the thread. If the notches are located in the cylindrical outer surface and the inner bore surface, they shall be machined on the circumferential axis of the bolt or stud.

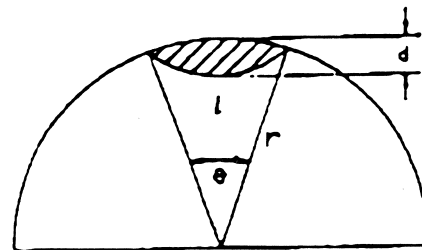
(c) Additional reflectors may be used provided they do not interfere with detection of the required notches.

(d) The finish on the surface of the basic calibration block shall be maintained similar to the finish existing during qualification.

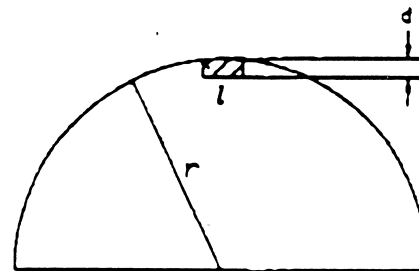
(e) The size and shape of the notches may vary depending upon the type of notch. Several configurations of notches are shown in Fig. L-13-1 representing straight, circular, and rectangular/square notches on the outside surface. Rectangular and circular notches are also possible for the inside surface of bore holes. Other shapes of notches on both the external and internal surfaces may be made.



(a) Straight Notch



(b) Circular Notch



(c) Rectangular/Square Notch

FIG. L-13-1 VARIOUS CALIBRATION NOTCH CONFIGURATIONS FOR OUTSIDE SURFACE REFLECTORS

The area of a straight cutter notch (see Fig. L-13-1a) is given by the following formula:

$$A = \left[\sin^{-1} \left(\frac{L}{2R} \right) \right] R^2 - 0.5 (L) (R - d)$$

where

A = area of notch

L = length of notch (cord)

R = minimum thread radius

d = depth of notch

$L/2R$ is in rads

The length L can be given as a function of d and R as follows:

$$L = \sqrt{8 dR - 4 d^2}$$

Several straight notch depths and lengths have been calculated for various sizes of 8-Thread Series (8-UN/8-UNR) studs and bolts and are presented in Table L-13.2.

L-20 CALIBRATION

L-21 General Requirements

Calibration shall be performed in accordance with T-460 and shall be performed using the complete ultrasonic examination system.

(a) Complete ultrasonic examination system calibration shall be performed each day prior to use of the system and for each bolt or stud configuration.

(b) For contact examination, the temperature differential between the examination and basic calibration block surfaces shall be within 25°F (14°C). For immersion examination, the couplant temperature for calibration shall be within 25°F (14°C) of the couplant temperature used during actual scanning. When either of these conditions is not achievable, appropriate compensations for velocity related variables (e.g., angle and sensitivity changes) shall be made.

(c) Any control which affects the instrument linearity (e.g., filters, reject, etc.) shall be in the off or minimum position for linearity check, calibration, and examination.

L-22 Calibration Confirmation

(a) *Instrument Linearity.* Instrument qualifications for screen height and amplitude control linearity shall be performed in accordance with Article 4, T-431.2.

(b) System Calibration Check

(1) A system calibration check shall verify the instrument sensitivity and sweep range calibration at the start and finish of the examinations, with any change in examination personnel, and at least every 12 hours during an examination.

(2) A system calibration check shall be performed when search units, shoes, couplants, cables, ultrasonic instruments, recording devices, or any other parts of the examination system are changed.

(c) *Sensitivity.* If the response from a calibration reflector notch has decreased more than 20% or 2 dB from its initial amplitude, all data records since the last calibration check shall be marked void or deleted. A new calibration shall be recorded and examinations performed since the last acceptable calibration check shall be repeated. If the response from a calibration reflector notch has increased more than 20% or 2 dB from its initial amplitude, recorded indications taken since the last valid calibration check may be reexamined with the correct calibration and their values changed on the data sheets.

L-23 Calibration Record

The following calibration data shall be recorded on a calibration sheet:

(a) calibration sheet identification and date, examination personnel;

(b) examination procedure number and revision;

(c) basic calibration block identification;

(d) ultrasonic instrument identification, serial number, and control settings;

(e) beam angle, couplant, and mode of wave propagation in the material;

(f) orientation of search unit with respect to the bolt or stud;

(g) search unit manufacturer, identification number, serial number, nominal frequency, and size;

(h) identification of fixtures and types or serial numbers of wedges and shoes (if used);

(i) search unit cable type, length, and number of connectors;

(j) times of initial calibration and subsequent calibration checks;

(k) amplitudes and sweep readings obtained from the calibration reflectors;

(l) if an electronic DAC is being used, a record shall be made of the resultant amplitudes and sweep readings obtained from the calibration reflectors after DAC correction; and

(m) calibration gain settings.

TABLE L-13.2
TYPICAL STRAIGHT NOTCH DIMENSIONS AS A FUNCTION OF NOTCH AREA AND STUD OR BOLT SIZE
DIMENSIONS FOR 8-THREAD SERIES (8-UN/8-UNR)

Bolt Nominal Size	Bolt Minor Dia.		Bolt [Note (1)] Area		Notch Area		Notch Depth		Notch Length		Notch Area as % of Bolt Area
	in.	mm	in. ²	mm ²	in. ²	mm ²	in.	mm	in.	mm	
2	1.8647	47.363	2.731	1 761.93	0.027	17.42	0.061	1.55	0.863	21.92	0.989
	1.9897	50.538	3.109	2 005.80	0.027	17.42	0.060	1.52	0.681	17.30	0.868
2.25	2.1147	53.713	3.512	2 265.80	0.027	17.42	0.058	1.47	0.691	17.55	0.769
	2.2397	56.888	3.940	2 541.93	0.027	17.42	0.057	1.45	0.705	17.91	0.685
2.5	2.3647	60.063	4.392	2 833.54	0.027	17.42	0.056	1.42	0.719	18.26	0.615
	2.4897	63.238	4.868	3 140.64	0.027	17.42	0.055	1.40	0.732	18.59	0.555
2.75	2.6147	66.413	5.369	3 463.86	0.027	17.42	0.054	1.37	0.744	18.90	0.503
	2.7397	69.588	5.895	3 803.22	0.027	17.42	0.053	1.35	0.755	19.18	0.458
3	2.8647	72.763	6.445	4 158.06	0.027	17.42	0.053	1.35	0.772	19.61	0.419
	2.9897	75.938	7.020	4 529.02	0.027	17.42	0.052	1.32	0.782	19.86	0.385
3.25	3.1147	79.113	7.619	4 915.47	0.027	17.42	0.051	1.30	0.791	20.09	0.354
	3.2397	82.288	8.243	5 318.05	0.027	17.42	0.050	1.27	0.799	20.29	0.328
3.5	3.3647	85.463	8.892	5 736.76	0.027	17.42	0.050	1.27	0.814	20.68	0.304
	3.4897	88.638	9.565	6 170.96	0.027	17.42	0.049	1.24	0.821	20.85	0.282
3.75	3.6147	91.813	10.262	6 620.63	0.027	17.42	0.049	1.24	0.836	21.23	0.263
	3.7397	94.988	10.984	7 086.44	0.027	17.42	0.048	1.22	0.842	21.39	0.246
4	3.8647	98.163	11.731	7 568.37	0.027	17.42	0.048	1.22	0.856	21.74	0.230
	3.9897	101.338	12.502	8 065.79	0.027	17.42	0.047	1.19	0.861	21.87	0.216
4.25	4.1147	104.513	13.297	8 578.69	0.059	38.06	0.078	1.98	1.122	28.50	0.444
	4.2397	107.688	14.118	9 108.37	0.059	38.06	0.078	1.98	1.139	28.93	0.418
4.5	4.3647	110.863	14.962	9 652.88	0.059	38.06	0.077	1.96	1.149	29.18	0.394
	4.4897	114.038	15.832	10 214.17	0.059	38.06	0.076	1.93	1.158	29.41	0.373
4.75	4.6147	117.213	16.725	10 790.30	0.059	38.06	0.075	1.91	1.167	29.64	0.353
	4.7397	120.388	17.644	11 383.20	0.059	38.06	0.075	1.91	1.183	30.05	0.334
5	4.8647	123.563	18.587	11 991.59	0.059	38.06	0.074	1.88	1.191	30.25	0.317
	4.9897	126.738	19.554	12 615.46	0.059	38.06	0.074	1.88	1.202	30.53	0.302
5.25	5.1147	129.913	20.546	13 255.46	0.059	38.06	0.073	1.85	1.213	30.81	0.287
	5.2397	133.088	21.563	13 911.59	0.059	38.06	0.072	1.83	1.220	30.99	0.274
5.5	5.3647	136.263	22.604	14 583.20	0.059	38.06	0.072	1.83	1.235	31.37	0.261
	5.4897	139.438	23.669	15 270.29	0.059	38.06	0.071	1.80	1.241	31.52	0.249
5.75	5.6147	142.613	24.760	15 974.16	0.059	38.06	0.071	1.80	1.250	31.75	0.238
	5.7397	145.788	25.874	16 692.87	0.059	38.06	0.070	1.78	1.260	32.00	0.228
6	5.8647	148.963	27.014	17 428.35	0.059	38.06	0.070	1.78	1.269	32.23	0.218

NOTE:

(1) Bolt area is calculated using bolt minor diameter.

L-30 EXAMINATION**L-31 General Examination Requirements**

Examination shall be performed by moving the search unit over the examination surface so as to scan the entire examination volume. As a minimum, each pass of the search unit shall overlap a minimum of 50% of the transducer (piezoelectric element) dimension perpendicular to the direction of the scan.

L-32 Rate of Search Unit Movement

The rate of search unit movement shall not exceed the maximum rate demonstrated to detect the calibration reflectors.

L-33 Scanning Sensitivity

If the noise level permits, the scanning sensitivity shall be a minimum of 6 dB above the reference level. However, evaluations shall be performed at the reference level.

L-34 Surface Preparation

The examination surfaces shall be free of irregularities (e.g., raised markings, scale, or loose foreign matter)

or coatings which interfere with ultrasonic wave transmission into the material.

L-35 Record

The following data shall be recorded:

(a) record identification, date, and time period of examination;

(b) identification and qualification levels of examination personnel;

(c) examination procedure and revision;

(d) applicable calibration sheet information;

(e) bolt or stud identification; and

(f) surfaces from which the examination is conducted (when the examination technique requires subdivisions of the examination surface or more than one examination surface, they shall be identified in the data record).

(g) *Indications*. For each indication required to be recorded by L-11 written procedure, the following information shall be recorded:

(1) search unit position;

(2) scan direction;

(3) metal path (sweep reading);

(4) signal amplitude at maximum response; and

(5) signal-to-noise ratio.

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ARTICLE 5

ULTRASONIC EXAMINATION METHODS FOR MATERIALS AND FABRICATION

T-510 SCOPE

This Article describes or references requirements which are to be used in selecting and developing [see T-110(c)] ultrasonic examination procedures for welds, parts, components, materials, and thickness determinations. This Article contains all of the basic technical and methodological requirements for ultrasonic examination. When examination to any part of this Article is a requirement of a referencing Code Section, the referencing Code Section shall be consulted for specific requirements for the following:

- Personnel Qualification/Certification Requirements
- Procedure Requirements and/or Techniques
- Examination System Characteristics
- Retention and Control of Calibration Blocks
- Acceptance Standards to Be Used for Evaluation
- Extent and Retention of Records
- Report Requirements
- Extent of Examination and/or Volume to be Scanned

T-520 GENERAL REQUIREMENTS

T-521 Basic Requirements and Terms Used

When this Article is specified by a referencing Code Section, the ultrasonic method described in this Article shall be used together with Article 1, General Requirements. Definitions of terms used in this Article are in Mandatory Appendix III of this Article. When SA, SB, and SE documents are referenced, they are located in Article 23.

01 T-522 Procedure Requirements

Ultrasonic examination shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable:

- (a) weld and/or material types and configurations to be examined, including thickness dimensions, and product form (casting, forging, plate, etc.);

- (b) the surface or surfaces from which the examination shall be performed;

- (c) surface condition;

- (d) couplant, brand name, or types;

- (e) technique (straight beam, angled beam, contact, and/or immersion);

- (f) angles and mode(s) of wave propagation in the material;

- (g) search unit type, frequency(ies), and transducer size(s);

- (h) special search units, wedges, shoes, or saddles;

- (i) ultrasonic instrument type(s);

- (j) description of calibration: blocks and techniques;

- (k) directions and extent of scanning;

- (l) data to be recorded and method of recording (manual or mechanized);

- (m) automatic alarm and recording equipment, or both;

- (n) rotating, revolving, or scanning mechanisms; and

- (o) post-examination cleaning.

T-523 General Examination Requirements for Other Than Thickness Measurements

T-523.1 Examination Coverage. The volume shall be examined by moving the search unit over the examination surface so as to scan the entire examination volume. Each pass of the search unit shall overlap a minimum of 10% of the transducer (piezoelectric element) dimension perpendicular to the direction of the scan.

T-523.2 Rate of Search Unit Movements. The rate of search unit movement for examination shall not exceed 6 in./sec (152 mm/s) unless calibration is verified at scanning speed.

T-523.3 Recording Sensitivity Level. For both manual and mechanized examinations recording of indications shall be made with respect to the reference level.

T-530 EQUIPMENT AND SUPPLIES**T-531 Frequency**

This examination shall be conducted with a pulse-echo ultrasonic instrument capable of generating frequencies over the range of at least 1 MHz to 5 MHz. Instruments operating at other frequencies may be used if equal or better sensitivity can be demonstrated and documented.

T-532 Screen Height Linearity

The ultrasonic instrument shall provide linear vertical presentation within $\pm 5\%$ of the full screen height for 20% to 80% of the calibrated screen height [base line to maximum calibrated screen point(s)]. The procedure for evaluating screen height linearity is provided in Appendix I and shall be performed at the beginning of each period of extended use (or every 3 months, whichever is less).

T-533 Amplitude Control Linearity

The ultrasonic instrument shall utilize an amplitude control accurate over its useful range to $\pm 20\%$ of the nominal amplitude ratio, to allow measurement of indications beyond the linear range of the vertical display on the screen. The procedure for evaluating amplitude control linearity is given in Appendix II and shall be performed at the beginning of each period of extended use (or every 3 months, whichever is less).

T-534 Checking and Calibration of Equipment

The proper functioning of the examination equipment shall be checked and the equipment shall be calibrated by the use of the calibration standard at the beginning and end of each examination, when examination personnel are changed, and at any time that malfunctioning is suspected, as a minimum.

If during any check it is determined that the testing equipment is not functioning properly, all of the product that has been tested since the last valid equipment calibration shall be reexamined.

T-536 Search Units

(a) Search units may contain either single or dual transducer elements.

(b) Search units with contoured contact wedges may be used to aid ultrasonic coupling. Calibration shall

be done with the contact wedges used during the examination.

T-540 APPLICATIONS**T-541 Material Product Forms**

T-541.1 Plate. Procedures used for ultrasonic examination of plate shall conform to the following applicable standards in Article 23, supplemented by T-510 and T-520, as well as T-541.1.1, T-541.1.2, and T-541.1.3:

(a) SA-435/SA-435M Standard Specification for Straight-Beam Ultrasonic Examination of Steel Plates

(b) SA-577/SA-577M Standard Specification for Ultrasonic Angle-Beam Examination of Steel Plates

(c) SA-578/SA-578M Standard Specification for Straight-Beam Ultrasonic Examination of Plain and Clad Steel Plates for Special Applications

(d) SB-548 Standard Method for Ultrasonic Inspection of Aluminum-Alloy Plate for Pressure Vessels

T-541.1.1 Equipment. The requirements for equipment shall be in accordance with T-530.

T-541.1.2 Calibration. The calibration requirements shall be in accordance with the applicable standard listed in T-541.1, or as supplemented by the referencing Code Section.

T-541.1.3 Examination. The requirements for examination shall be in accordance with the applicable standard listed in T-541.1. Examinations for final acceptance shall be performed after the plate rolling to size and after heat treatment.

T-541.2 Forgings and Bars. Procedures used for ultrasonic examination of forgings and bars shall conform to the following applicable standards in Article 23, supplemented by T-510 and T-520, as well as T-541.2.1, T-541.2.2, and T-541.2.3:

(a) SA-388 Standard Practice for Ultrasonic Examination of Heavy Steel Forgings

(b) SA-745 Standard Practice for Ultrasonic Examination of Austenitic Steel Forgings

T-541.2.1 Equipment. The requirements for equipment shall be in accordance with T-530.

T-541.2.2 Calibration. The calibration requirements shall be in accordance with the applicable standard listed in T-541.2.

T-541.2.3 Examination. The requirements for examination shall be selected in accordance with the applicable standard listed in T-541.2, except as listed in (a) through (d) below.

(a) All forgings and bars shall be examined by the ultrasonic method, using the straight beam technique.

(b) Ring forgings and other hollow forgings shall, in addition, be examined using the angle beam technique in two circumferential directions, unless wall thickness or geometric configuration makes angle beam examinations impractical.

(c) In addition to (a) and (b) above, ring forgings made to fine grain melting practices and used for vessel shell sections shall also be examined by angle beam technique in two axial directions.

(d) Immersion techniques may be used.

01 T-541.3 Tubular Products. Procedures used for ultrasonic examination of pipe, tubing, and fittings shall conform to the following applicable standards in Article 23, supplemented by T-510 and T-520, as well as T-541.3.1, T-541.3.2, and T-541.3.3.

(a) SE-213 Standard Practice for Ultrasonic Examination of Metal Pipe and Tubing

(b) SE-273 Standard Practice for Ultrasonic Examination of Longitudinal and Welded Pipe and Tubing

T-541.3.1 Equipment. The requirements shall be in accordance with T-530.

T-541.3.2 Calibration. The calibration requirements shall be selected in accordance with the applicable standard listed in T-541.3, as well as (a) and (b) below.

(a) The calibration block shall be of the same nominal diameter and thickness and of the same nominal composition and heat treatment condition as the product that is being examined. The calibration reflectors shall be axial notches or grooves on the outside and the inside surfaces of the calibration block, and shall have a length of approximately 1 in. (25 mm) or less, a width not to exceed $\frac{1}{16}$ in. (1.6 mm), and a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the nominal wall thickness. The calibration block may be the product being examined.

(b) The calibration block shall be long enough to simulate the handling of the product being examined through the examination equipment. When more than one calibration reflector is placed in a calibration block, the reflector shall be located so that indications from each reflector are separate and distinct, without mutual interference or amplification.

T-541.3.3 Examination. The requirements for examination shall be selected in accordance with the applicable standard listed in T-541.3.

T-541.4 Castings. When ultrasonic examination of ferritic castings is required by the referencing Code Section, all sections, regardless of thickness, shall be

examined in accordance with SA-609, supplemented by T-510 and T-520, as well as T-541.4.1, T-541.4.2, and T-541.4.3.

T-541.4.1 Equipment. The requirements for equipment shall be in accordance with T-530, supplemented by (a) and (b) below.

(a) The transducer shall be 1 or $1\frac{1}{8}$ in. (25 or 29 mm) in diameter, or 1 sq in. (645 mm²), maximum.

(b) 1 MHz search units shall be used for examination, although other frequencies may be used for evaluation if equal or better sensitivity can be demonstrated and documented.

T-541.4.2 Calibration

T-541.4.2.1 Calibration Blocks. The block or blocks required to establish the examination sensitivity across the full thickness of the castings to be examined shall be made of material of the same specification, grade, product form, heat treatment, and thickness $\pm 25\%$ as the castings to be examined. The surface finish of the calibration block shall be representative of the examination surface of the casting to be examined.

(a) *Straight Beam.* Calibration blocks meeting the requirements described in T-541.4.2.1 and in SA-609 shall be used.

(b) *Angle Beam.* The basic calibration block shall be as shown in Fig. T-541.4.1.2(b). Holes of larger or smaller diameters, V- or square notches may also be placed in the calibration block to provide reference reflectors for evaluation purposes. These additional holes and notches shall be located so as not to interfere with the responses from the basic calibration reflectors.

T-541.4.2.2 Calibration Method

(a) *Straight Beam.* The examination sensitivity adjustment shall be established as described in SA-609, exclusive of paragraph 7.3, on the calibration block described in T-541.4.2.1(a).

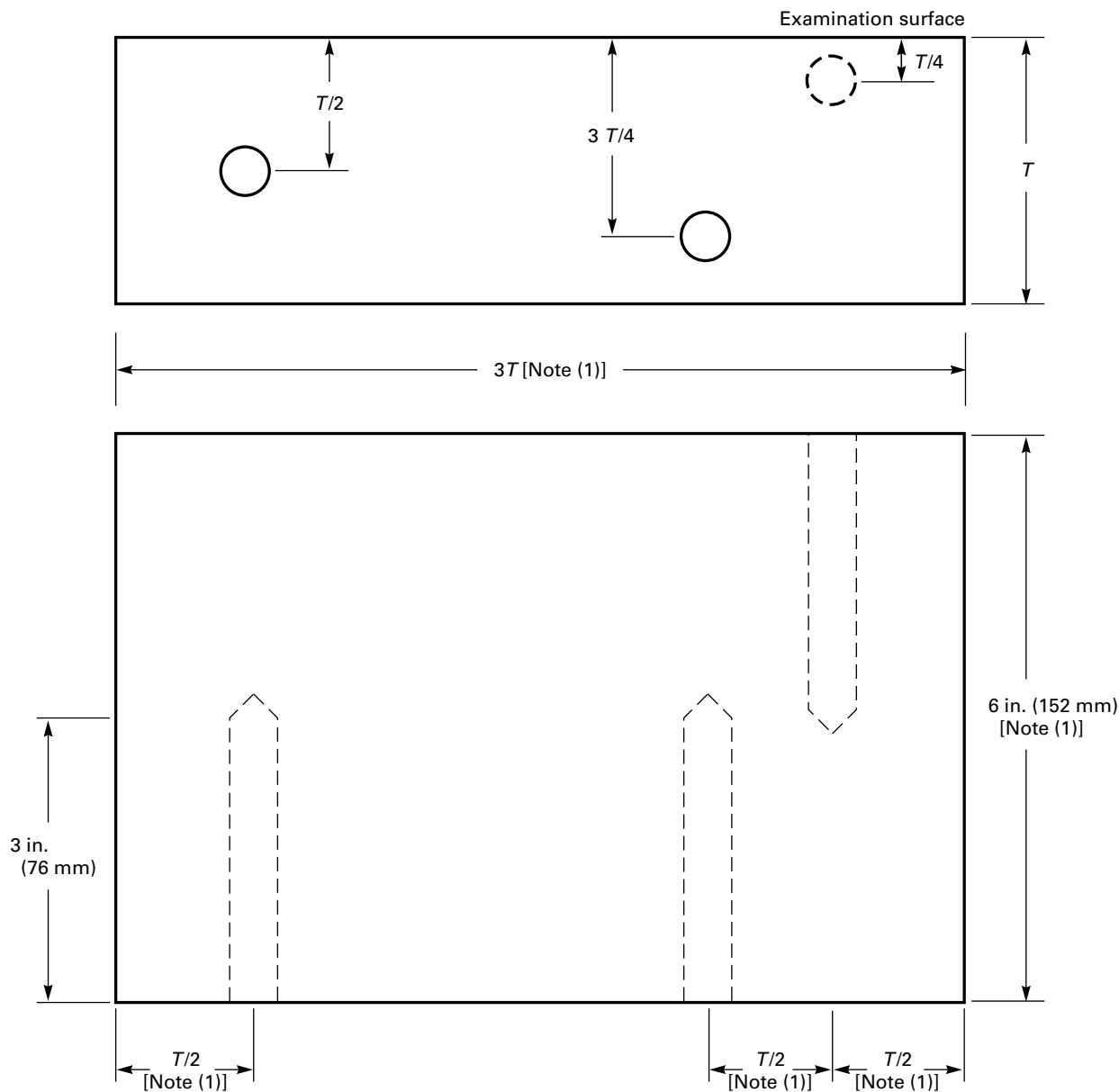
(b) *Angle Beam.* The examination sensitivity shall be established at 80% of full screen height using the side-drilled hole producing the largest response. The distance amplitude correction (DAC) curve shall be constructed by utilizing the responses from the side drilled hole reflectors in the angle beam calibration block [Fig. T-541.4.1.2(b)] covering the examination distance range in the casting to be examined.

T-541.4.3 Examination. The requirements for examination shall be in accordance with SA-609, and supplemented by (a) and (b) below.

(a) A supplementary angle beam examination shall be performed on castings or areas of castings where a back reflection cannot be maintained during the

Fig. T-541.4.1.2(b)

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GENERAL NOTE:
HOLES: Drilled and reamed essentially parallel to the examination surface. The tolerance on hole diameter shall be $\pm 1/32$ in. (0.8 mm). The tolerance on location through the thickness shall be $\pm 1/8$ in. (3.2 mm).

Material Thickness T	Diameter D	Holes Required
$1/2$ in. (13 mm) through 2 in. (51 mm)	$1/4$ in. (6 mm)	$T/2$
Greater than 2 in. (51 mm)	$3/8$ (10 mm)	$T/4$, $T/2$, and $3T/4$

NOTE:
(1) Minimum.

FIG. T-541.4.1.2(b) ANGLE BEAM CALIBRATION BLOCK

TABLE T-541.5.1
FLAT BOTTOM HOLE REQUIREMENTS

$D = d \pm 1$ in.	(25 mm)	Flat Bottom Hole Diam. $\pm \frac{1}{32}$ in.	(0.8 mm)
Up to 1 in.	(25 mm)	$\frac{1}{16}$ in.	(1.6 mm)
Over 1 to 2 in.	(25 mm to 51 mm)	$\frac{1}{8}$ in.	(3.2 mm)
Over 2 to 3 in.	(51 mm to 76 mm)	$\frac{3}{16}$ in.	(4.8 mm)
Over 3 to 4 in.	(76 mm to 102 mm)	$\frac{5}{16}$ in.	(7.9 mm)
Over 4 in.	(102 mm)	$\frac{3}{8}$ in.	(9.5 mm)

GENERAL NOTE:

Flat bottom hole machined to a minimum depth of $\frac{1}{2}$ in. (13 mm) parallel to the transducer contact surface.

TABLE T-541.5.2
CALIBRATION BLOCK DESIGNATION PER LENGTH
AND HOLE LOCATION

Block Designation	Block Length L	Flat Bottom Hole Location L
A	$\ell/8$ + hole depth	$D/4$ of block end
B	$\ell/2$ + hole depth	Center line of block end
C	$\ell/4$ + hole depth	Center line of block end

GENERAL NOTE: A tolerance of $\pm 5\%$ may be applied.

straight beam examination, or where the angle between the front and back surfaces of the castings exceeds 15 deg.

(b) The requirements for extent of examination and acceptance criteria shall be as required by the referencing Code Section.

T-541.5 Bolting Material. Procedures used for ultrasonic examination of bolting material bolts, studs, and nuts shall conform to the requirements of SA-388 as modified by the following subparagraphs. Calibration blocks in accordance with Tables T-541.5.1 and T-541.5.2 shall be used for straight beam calibration. Tables T-541.5.1 and T-541.5.2 show relationships between examined material diameter d , length ℓ , and calibration block diameter D , and length L . Flat bottom holes shall be as shown in Fig. T-541.5.1 drilled a minimum of $\frac{1}{2}$ in. (38 mm) deep in the axial direction of the block.

Calibration block material and examination surface finish shall be the same or equivalent to the bolting under examination.

T-541.5.1 Straight Beam, Radial Scan. Bolting materials shall be examined radially prior to threading. The examination shall be in accordance with the following.

(a) *Technique.* The examination shall be performed using pulse-echo, straight beam equipment with the contact or immersion technique.

(b) *Calibration.* The sensitivity shall be established using the reflection indication from the side of the hole in calibration block A, at the radial metal paths of $D/4$ and $3D/4$. Select the hole indication at the metal path which gives the greatest amplitude and set the gain control so that this indication is $80\% \pm 5\%$ of full screen height. Without changing the instrument controls, obtain maximum amplitudes from the other metal path. Mark the indication amplitudes on the cathode ray tube, connect the adjacent points and extend the DAC to cover the range of examination.

(c) *Examination.* Scanning shall be performed helically or circumferentially in overlapping paths so as to cover the entire accessible cylindrical surface of the bar.

(d) *Evaluation.* Any imperfection which causes an indication in excess of 20% of DAC shall be investigated to the extent that it can be evaluated in terms of the acceptance standards of the referencing Code Section.

T-541.5.2 Straight Beam, Axial Scan. Bolting materials shall be examined axially before or after threading. The examination shall be conducted in accordance with the following.

(a) *Technique.* The examination shall be performed from both end surfaces of the material using pulse-echo, straight beam equipment with the contact or immersion technique.

(b) *Calibration.* The sensitivity shall be adjusted to give an 80% of full screen amplitude from the flat bottom hole in the block which gives the highest amplitude. Mark this amplitude and the amplitude of the flat bottom hole in the lower amplitude block on the screen, and connect the two marks with a straight line extending to the entry surface indication. This is the DAC line. If the lower amplitude block gives less than 20% of full screen amplitude, prepare an $\ell/4$ + hole depth block and construct two DAC lines to cover the examination metal path range. This is accomplished by setting the sensitivity to give an 80% of full screen amplitude from the flat bottom hole in the $\ell/8$ or $\ell/4$ block which gives the higher amplitude. Mark this amplitude and the amplitude of the lower amplitude block on the screen and connect the two marks with a straight line extending to the entry surface indication. Record the sensitivity setting which will be used in

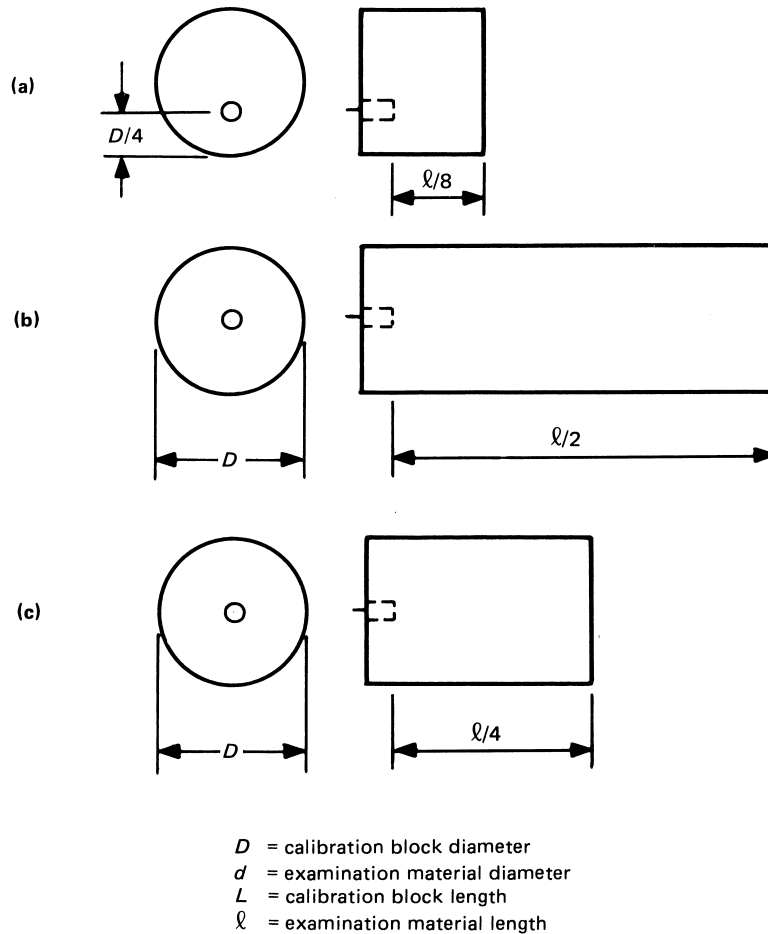


FIG. T-541.5.1 STRAIGHT BEAM (FBH) CALIBRATION BLOCK

the examination of the end quarters of length of the bolting material. Next set the sensitivity to give an 80% of full screen amplitude from the flat bottom hole in the $l/4$ or $l/2$ block which gives the higher amplitude. Mark this amplitude and the amplitude of the lower amplitude block on the screen and connect the two marks with a straight line. Record the sensitivity setting which will be used in the examination of the two middle quarters of length of the bolting material.

(c) *Examination.* Surface preparation — both end surfaces of the bolting material shall be flat and normal to the bolt axis. Record all indications exceeding 20% DAC in the quarter of length applicable to the sensitivity setting.

(d) *Evaluation.* Any reflector which causes an indication in excess of 20% of DAC shall be investigated to the extent that it can be evaluated in terms of the acceptance standards of the referencing Code Section.

T-541.5.3 Inservice Examination of Bolts and Studs

T-541.5.3.1 When inservice examination of bolts and studs is specified by the referencing Code Section, the examination shall be performed in accordance with Appendix L of Article 4.

T-541.5.3.2 For materials with diameters 2 in. and greater, basic calibration blocks shall have reflectors in accordance with Appendix L.

T-541.5.3.3 For bolts and studs less than 2 in. (51 mm) in diameter, a calibration block shall be made to the requirements of Appendix L, except for the size of the reflectors. The reflector area shall be established as one thread depth for the threads used on the bolt or stud. The area of the reflector is determined by the depth of a straight notch and the resulting length of the notch. Any of the types of notches illustrated in

Article 4, Appendix L, Fig. L-13-1 may be used as long as the area does not exceed that calculated for a straight notch one thread depth deep.

T-541.5.3.4 Any discontinuity which causes an indication in excess of that produced by the calibration reflector shall be investigated. The size and location of all such reflectors shall be evaluated in accordance with the acceptance standards of the referencing Code Section.

T-542 Welds

These paragraphs describe the requirements for ultrasonic examination of full penetration welds in wrought (rolled, drawn, forged, or extruded) and cast materials.

These requirements are established for the ultrasonic detection, location, and evaluation of ultrasonic reflectors within the weld, heat affected zone, and adjacent material. The two general examination classifications are:

- (a) welds in ferritic product forms other than pipe;
- (b) ferritic welds in ferritic pipe.

For austenitic and high nickel alloy welds, see T-542.8.5.

T-542.1 Equipment. The requirements for equipment shall be in accordance with T-530.

T-542.2 Calibration

T-542.2.1 Basic Calibration Block(s). The basic calibration reflectors shall be used to establish a primary reference response of the equipment. The basic calibration reflectors may be located either in the component material or in a basic calibration block. Where the block thickness ± 1 in. (25 mm) spans two of the weld thickness ranges shown in Fig. T-542.2.1, the block's use shall be acceptable in those portions of each thickness range covered by 1 in. (25 mm).

T-542.2.1.1 Basic Calibration Block Material

(a) *Block Selection.* The material from which the block is fabricated shall be of the same product form, and material specification or equivalent P-Number grouping as one of the materials being examined. For the purposes of this paragraph, P-Nos. 1, 3, 4, and 5 materials are considered equivalent. For calibration blocks for dissimilar metal welds, the material selection shall be based on the material on the side of the weld from which the examination will be conducted: if the examination will be conducted from both sides, calibration reflectors shall be provided in both materials. Where two or more base material thicknesses are in-

volved, the calibration block thickness shall be determined by the average thickness of the weld.

(b) *Clad.* Where the component material is clad, the block shall be clad by the same welding procedure as the production part. Where the automatic method is impractical, deposition of clad shall be by the manual method. It is desirable to have component materials which have been clad before the drop outs or prolongations are removed.

(c) *Heat Treatment.* The calibration block shall receive at least the minimum tempering treatment required by the material specification for the type and grade, and also a postweld heat treatment of at least 2 hr, if the calibration block contains weld(s) other than cladding.

(d) *Surface Finish.* The finish on the surfaces of the block shall be representative of the surface finishes on the components.

(e) *Block Quality.* The calibration block material shall be completely examined with a straight beam search unit. Areas that contain an indication exceeding the remaining back reflection shall be excluded from the beam paths required to reach the various calibration reflectors.

T-542.3 Calibration Reflectors

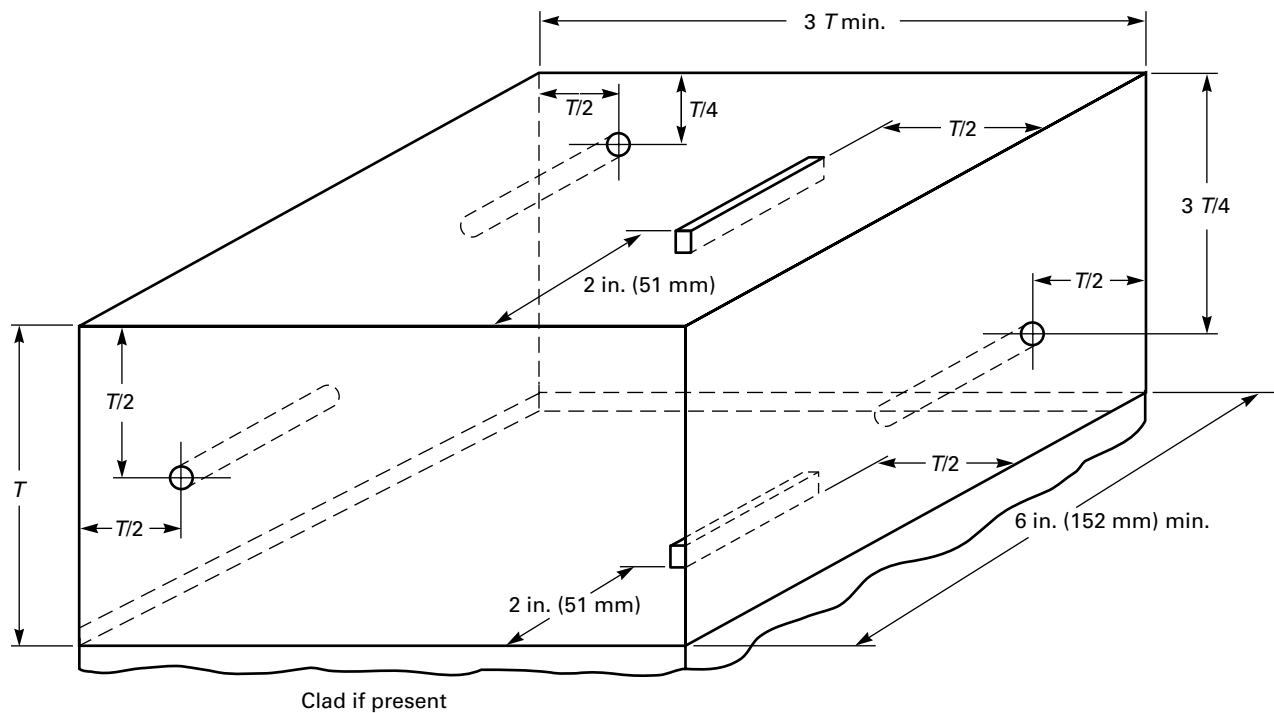
T-542.3.1 Basic Calibration Reflectors. The calibration reflectors are specified in T-542.2.1 and T-542.8.1.2.

T-542.3.2 Additional Reflectors. Additional reflectors may be installed; these reflectors shall not interfere with establishing the primary reference.

T-542.3.3 Calibration Block Configuration. Calibration block configuration requirements are specified in T-542.2.1 and T-542.8.1.1.

T-542.3.4 Materials With Diameters Greater Than 20 in. (508 mm). For examinations in materials where the examination surface diameter is greater than 20 in. (508 mm), a block of essentially the same curvature, or alternatively, a flat basic calibration block, shall be used.

T-542.3.5 Materials With Diameters 20 in. (508 mm) and Less. The basic calibration block shall be curved for materials with diameters 20 in. (508 mm) and less. Except where otherwise stated in this Article, a single curved basic calibration block may be used to calibrate the examination on surfaces in the range of curvature from 0.9 to 1.5 times the basic calibration block diameter. For example, an 8 in. (203 mm) diameter curved block may be used to calibrate the examination on surfaces in the range of curvature from 7.2 in. to



Weld thickness, t , in. (mm)	Basic Calibration Block Thickness, T , in. (mm)	Hole Diameter, in. (mm)	Notch Size, in. (mm)
1 or less (25 or less)	$\frac{3}{4}$ or t (19 or t)	$\frac{3}{32}$ (2.4)	Width = $\frac{1}{8}$ to $\frac{1}{4}$ (3.2 to 6.4)
Over 1 through 2 (25 through 51)	$1\frac{1}{2}$ or t (38 or t)	$\frac{1}{8}$ (3.2)	Depth = 2% T or 0.04 whichever is greater, into the base metal (2% T or 0.1, whichever is greater, into the base metal.)
Over 2 through 4 (51 through 102)	3 or t (76 or t)	$\frac{3}{16}$ (4.8)	
Over 4 through 6 (102 through 152)	5 or t (127 or t)	$\frac{1}{4}$ (6.4)	
Over 6 through 8 (152 through 203)	7 or t (178 or t)	$\frac{5}{16}$ (7.9)	
Over 8 through 10 (203 through 254)	9 or t (230 or t)	$\frac{3}{8}$ (9.5)	
Over 10 (254)	$t \pm 1$ ($t \pm 25$)	[Note (1)]	Length = 2 min. (51 min.)

GENERAL NOTES:

- (a) Holes shall be drilled and reamed a minimum of $1\frac{1}{2}$ in. (38 mm) deep, essentially parallel to the examination surface.
 (b) Alternatively, the block may be constructed as shown in Article 4, Appendix J, Fig. J-10.
 (c) Curved surfaces: for curved surfaces, two curved blocks, one for each representative curvature; or two sets of calibration reflectors oriented 90 deg. from each other shall be used.
 (d) Notches may be provided as required.
 (e) The tolerance for hole diameter shall be $\pm \frac{1}{32}$ in. The tolerance on notch depth shall be +10 and -20%. The tolerance on hole location through the thickness shall be $\pm \frac{1}{8}$ in. (3.2 mm).

NOTE:

- (1) For each increase in weld thickness of 2 in. (51 mm) or fraction thereof over 10 in. (254 mm), the hole diameter shall increase $\frac{1}{16}$ in. (1.6 mm).

FIG. T-542.2.1 BASIC CALIBRATION BLOCK

12 in. (183 mm to 305 mm) diameter. The curvature range from 0.94 in. to 20 in. (25 mm to 508 mm) diameter requires 6 block curvatures as indicated in Fig. T-542.3.5 for any thickness range.

T-542.3.6 As an alternative to the requirements in T-542.3.4 when examining from the convex surface by the straight beam contact technique, Appendix A may be used.

T-542.4 System Calibration

T-542.4.1 General Requirements. Calibration shall include the complete ultrasonic examination system.

T-542.4.2 Calibration Measurements. Each calibration shall be performed from the surface (clad or unclad) corresponding to the surface of the component from which the examination will be performed.

T-542.4.3 Techniques. Article 4, Appendices B and C, gives general techniques for both angle beam and straight beam calibrations. Other techniques may be used.

T-542.4.4 Angle Beam Calibration. As applicable, the calibration shall provide the following measurements (Article 4, Appendix B contains a general technique):

- (a) sweep range calibration;
- (b) distance–amplitude correction;
- (c) position calibration;
- (d) echo amplitude measurement from the surface notch in the basic calibration block.

When an electronic distance–amplitude correction device is used, the primary reference responses from the basic calibration block shall be equalized over the distance range to be employed in the examination. The response equalization line shall be at a screen height of 40% to 80% of full screen height.

T-542.4.5 Straight Beam Calibration. The calibration shall provide the following measurements (Article 4, Appendix C gives a general technique):

- (a) sweep range calibration;
- (b) distance–amplitude correction.

When an electronic distance–amplitude correction device is used, the primary reference response shall be equalized on the basic calibration block at a screen height between 40% and 80% of full screen height over the distance range to be employed in the examination.

T-542.4.6 Calibration Check on Basic Calibration Block. When any part of the examination system is changed, a calibration check shall be made on the basic calibration block to verify that $\frac{1}{4}T$, $\frac{1}{2}T$, and $\frac{3}{4}T$ points on the sweep and distance amplitude correction

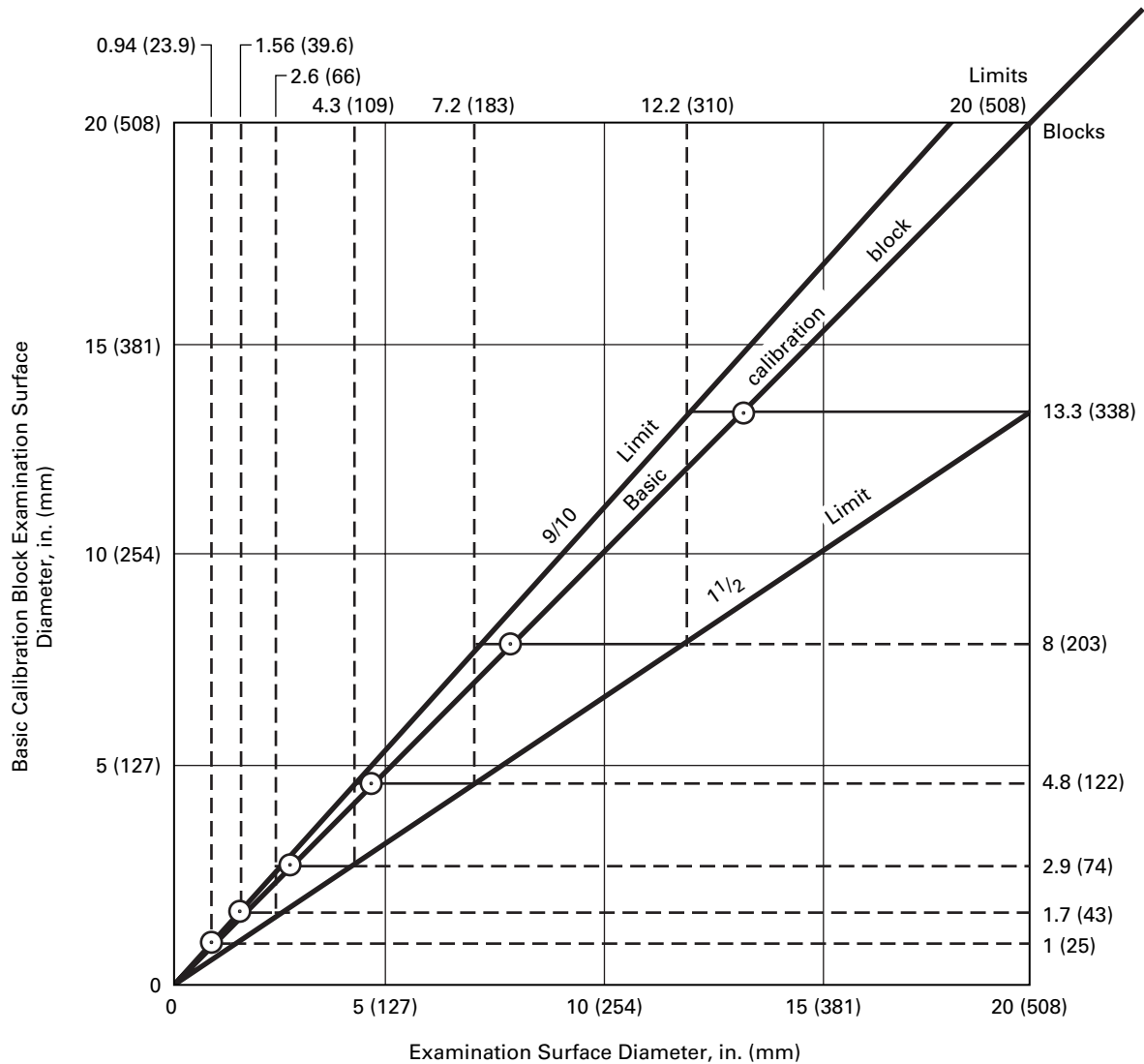
values recorded satisfy the requirements of T-542.5. Where original calibration data exist for the part of the system replaced, a check as permitted in T-542.4 may be used.

T-542.4.7 Calibration Check on Basic Calibration Block or Simulator Check. A calibration check on at least one of the basic reflectors in the basic calibration block or a check using a simulator shall be made at the finish of each examination or series of similar examinations, every 4 hr during the examination, and when examination personnel (except for automated equipment) are changed. The sweep and distance amplitude correction values recorded shall satisfy the requirements of T-542.5.

T-542.4.8 Simulator Check. Any simulator checks that are used shall be correlated with the original calibration on the basic calibration block during the original calibration. The simulator checks may use different types of calibration reflector or block (such as IIW) and/or electronic simulation. However, the simulation used shall be completely identifiable on the calibration sheet(s). The simulator check shall be made on the entire examination system. The entire system does not have to be checked in one operation; however, for its check, the search unit shall be connected to the ultrasonic instrument and checked against a calibration reflector. Accuracy of the simulator checks shall be confirmed, using the basic calibration block, at the conclusion of each period of extended use, or every 3 months, whichever is less. The requirements for calibration confirmation of T-542.5 and T-542.5.1 shall be met.

T-542.5 Calibration Confirmation. Calibration (T-542.4.3) shall be performed prior to use of the system in the thickness range under examination. A calibration check shall verify the sweep range calibration and distance–amplitude correction [T-542.4.4(a) or T-542.4.5(a)] as defined in T-542.4.1.

T-542.5.1 Sweep Range Correction. If a point on the DAC curve has moved on the sweep line more than 10% of the sweep reading or 5% of full sweep, whichever is greater, correct the sweep range calibration and note the correction in the examination record. If reflectors are recorded on the data sheets, those data sheets shall be voided and a new calibration shall be recorded. All recorded indications since the last valid calibration or calibration check shall be reexamined with the corrected calibration and their values shall be changed on the data sheets.



GENERAL NOTES:

- Plot examination surface of basic calibration block on diagonal (45 deg) line.
- Draw horizontal line through that point from the 9/10 to the $1\frac{1}{2}$ limit line.
- The ends of this line read on the horizontal scale give the range of examination surface diameters which may be examined with a system calibrated on this block.
- Thickness range requirements shall also be satisfied.

FIG. T-542.3.5 RATIO LIMITS FOR CURVED SURFACES

T-542.5.2 DAC Correction. If a point on the distance–amplitude correction (DAC) curve has decreased 20% or 2 dB of its amplitude, all data sheets since the last calibration or calibration check shall be marked void. A new calibration shall be made and recorded and the area covered by the voided data shall be reexamined. If any point of the distance–amplitude correction (DAC) curve has increased more than 20% or 2 dB of its amplitude, all recorded indications since the last valid calibration or calibration check shall be reexamined with the corrected calibration and their values shall be changed on the data sheets.

T-542.6 Welds in Wrought and Cast Ferritic Product Forms, Excluding Pipe

T-542.6.1 Basic Calibration

T-542.6.1.1 Basic Calibration Block. The basic calibration block shall be as specified in T-542.2.1, and shall use side-drilled holes as calibration reflectors. See Fig. T-542.2.1.

T-542.6.1.2 Angle Beam Calibration. Angle beam calibrations shall be performed as described in Article 4, Appendix B, supplemented as follows:

T-542.6.1.3 Frequency. The nominal frequency shall be 2.25 MHz unless variables such as production material grain structure require the use of other frequencies to assure adequate penetration or better resolution.

T-542.6.1.4 Beam Angle. An angle shall be selected as appropriate for the configuration being examined.

T-542.6.1.5 Distance–Amplitude Correction (DAC) Exemption. A DAC is not required where the examination is limited to one-half V-path in a material less than 1 in. thick, in which case the amplitude level from a single calibration reflector shall be used.

T-542.6.1.6 Straight Beam Calibration. Calibration and straight beam examination shall be performed in accordance with Article 4, Appendix C, supplemented as follows.

T-542.6.1.7 Frequency. The nominal frequency shall be 2.25 MHz unless variables such as production material grain structure require the use of other frequencies to assure adequate penetration or better resolution.

T-542.7 Examination of Welds

T-542.7.1 Surface Preparation

T-542.7.1.1 Base Metal. The base metal on each side of the weld shall be free of weld spatter,

surface irregularities, or foreign matter that might interfere with the examination.

T-542.7.1.2 Weld Metal. Where the weld surface interferes with the examination, the weld shall be prepared as needed to permit examination.

T-542.7.2 Scanning

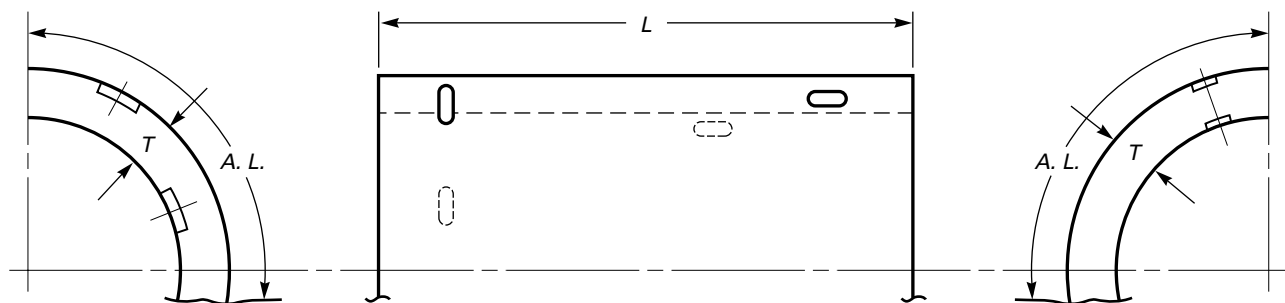
T-542.7.2.1 Straight Beam. The scanning of the adjacent base metal shall be performed to detect reflectors that might affect interpretation of angle beam results, and is not to be used as an acceptance-rejection examination. Locations and areas of such reflectors shall be recorded.

T-542.7.2.2 The weld and base metal shall be scanned, where required by the referencing Code Section to the extent possible with the straight beam search unit. The scanning shall be performed at a gain setting of at least two times the primary reference level. Evaluation shall be performed with respect to the primary reference level.

T-542.7.2.3 Angle Beam Scanning for Reflectors Oriented Parallel to the Weld. The angle beam shall be directed at approximate right angles to the weld axis from two directions where possible. The search unit shall be manipulated so that the ultrasonic energy passes through the required volumes of weld and adjacent base metal. The scanning shall be performed at a gain setting at least two times the primary reference level. Evaluation shall be performed with respect to the primary reference level.

T-542.7.2.4 Angle Beam Scanning for Reflectors Oriented Transverse to the Weld. The angle beam shall be directed essentially parallel to the weld axis. The search unit shall be manipulated so that the angle beam passes through the required volumes of weld and adjacent base metal specified by the referencing Code Section. The scanning shall be performed at a gain setting at least two times the primary reference level. Evaluation shall be performed with respect to the primary reference level. The search unit shall be rotated 180 deg. and the examination repeated.

T-542.7.2.5 Evaluation. Any imperfection which causes an indication in excess of 20% DAC shall be investigated to the extent that it can be evaluated in terms of the acceptance standards of the referencing Code Section.



Typical Block Dimensions

Length L 8 in. or $8T$, whichever is greater

Minimum Arc Length $A.L.$

(1) for O.D. or 4 in. (102 mm) or less: 270 deg.

(2) for O.D. greater than 4 in. (102 mm): the greater of $3T$ or 8 in. (203 mm)

Specific Notch Dimensions

Length L — 1 in. (25 mm) minimum

Depth D — 10% T with tolerance $D + 10\%$
 $- 20\%$ of depth

Width — $\frac{1}{8}$ in. to $\frac{1}{4}$ in. (3.2 mm to 6.4 mm)

Location — not closer than T from any block edge

FIG. T-542.8.1.1 ANGLE BEAM CALIBRATION (PIPE WELDS)

T-542.8 Ferritic Welds in Ferritic Pipe

T-542.8.1 Basic Calibration

T-542.8.1.1 Basic Calibration Block (See Fig. T-542.8.1.1). The basic calibration block for weldments shall be a section of pipe of the same nominal size, schedule, heat treatment, and material specification or equivalent P-Number grouping as one of the materials being examined. For the purposes of this paragraph, P-Nos. 1, 3, 4, and 5 materials are considered equivalent. The block size and reflector locations shall be adequate to perform calibration for the beam angles used. The surface finish of the calibration block shall be representative of the surface finish of the piping.

T-542.8.1.2 Basic Calibration Reflectors. The basic calibration reflectors shall be longitudinal and with circumferential notches on both the inner and outer surfaces. The sizes and locations of the calibration reflectors are shown in Fig. T-542.8.1.1.¹

T-542.8.2 Angle Beam Calibration

T-542.8.2.1 Frequency. The nominal frequency shall be 2.25 MHz, unless attenuation or a need for

greater resolution makes some other frequency more suitable.

T-542.8.2.2 The nominal beam angle of 45 deg. shall generally be used but other angles may be used where appropriate for the configuration being examined.

T-542.8.2.3 Distance–Amplitude Correction (DAC). A DAC curve is required for all pipe welds. For examination of a full wall thickness, the notches shall be used as calibration reflectors. The angle beam shall be directed toward the calibration reflector that yields the maximum response, setting the instrument adjustment to yield 80% of screen height. The search unit shall then be manipulated, without changing instrument settings, to obtain the maximum responses from the calibration reflectors at the distance increments necessary to generate a 3-point DAC curve.

T-542.8.2.4 Selection of Calibration Reflectors. A side-drilled hole may be used for initial acceptance of a pipe weld, provided that it can be demonstrated that the hole calibration produces a sensitivity equal to or greater than the notch calibration.

T-542.8.2.5 Straight Beam Calibration. Straight beam examination, when required by the refer-

¹ When side-drilled holes are to be used for calibration, the block shall be as shown in Fig. T-542.2.1 (see T-542.8.2.5).

encing Code Section, or, if needed to evaluate an angle beam indication, shall be calibrated on the side drilled holes in the basic calibration block. When required, the straight beam calibration shall be performed to the requirements of Article 4, Appendix C.

T-542.8.3 Examination of Pipe Weldments

T-542.8.3.1 Surface Preparation. Surface preparation shall be performed to the requirements of T-542.7.1.

T-542.8.4 Scanning of Pipe Weldments

T-542.8.4.1 Straight Beam. When straight beam scanning is required, it shall be performed according to the requirements of T-542.7.2.1.

T-542.8.4.2 Angle Beam. Angle beam scanning of pipe welds shall be performed according to the requirements of T-542.7.2.3 and T-542.7.2.4.

T-542.8.4.3 Evaluation. Any imperfection which causes an indication in excess of 20% DAC shall be investigated to the extent that it can be evaluated in terms of the acceptance standards of the referencing Code Section.

T-542.8.5 Austenitic and High Nickel Alloy Welds

T-542.8.5.1 Discussion. Ultrasonic examination of austenitic and high nickel alloy welds is usually more difficult than in ferritic materials, because of the wide variations that may occur in the acoustic properties of austenitic and high nickel alloy welds, even those in alloys of the same composition, product form, and heat treatment. It may, therefore, be necessary to modify and/or supplement the provisions of this Article in accordance with T-150(a) when examining such welds.

T-543 Cladding

The pulse-echo ultrasonic techniques described in these paragraphs shall be used where ultrasonic examination of weld metal overlay cladding is required by a referencing Code Section. Examination of roll bonded and explosive clad plate shall be performed in accordance with SA-578/SA-578M when required by a referencing Code Section.

The techniques described herein shall be used for examination of weld deposited cladding. Technique One shall be used to examine for bond and clad flaw indications or Technique Two shall be used to examine for lack of bond.

T-543.1 Equipment

T-543.1.1 Equipment for Technique One. Dual search units using an angled pitch-catch technique may be used. The included angle between the beam paths shall be such that the maximum sensitivity of the search unit is in the area of interest. The total transducer area shall not exceed $\frac{1}{2}$ sq in. (322 mm²). A nominal frequency of 2.25 MHz shall be used; however, other frequencies may be used to achieve the necessary resolution.

T-543.1.2 Equipment for Technique Two. Straight beam search units with a maximum transducer area of 1 sq in. (645 mm²) shall be used. A nominal frequency of 2.25 MHz shall be used; however, other frequencies may be used to achieve the necessary resolution.

T-543.1.3 Calibration Block for Technique One. A calibration block clad by the same welding procedure as the production part shall be used. The surface condition shall be representative of that of the production part. Either a side-drilled hole $\frac{1}{16}$ in. (1.6 mm) diameter by $1\frac{1}{2}$ in. (38 mm) minimum depth shall be drilled into the block at the clad interface, or a $\frac{1}{8}$ in. (3.2 mm) diameter flat bottomed hole shall be drilled through the base metal to the clad interface. The thickness of the base material shall be at least twice the thickness of the cladding. The calibration block is shown in Fig. T-543.2.

T-543.1.4 Calibration Block for Technique Two. For clad bond examination, a calibration block clad by the same welding procedure as the production part shall be used. The surface condition shall be representative of the cladding on the production part. A $\frac{3}{8}$ in. (9.5 mm) flat bottom hole shall be drilled to the weld overlay interface. This hole may be drilled from the base metal or weld overlay side. Other calibration reflectors may be used provided it is demonstrated that equal or greater sensitivity is attained. The thickness of the base material examined shall be within 1 in. (25 mm) of the calibration block thickness when examined from the base metal surface. The thickness of the base material on the calibration block shall be at least twice the thickness of the cladding, when examining from the clad surface.

T-543.2 Calibration

T-543.2.1 Calibration for Technique One. Calibration shall be accomplished by placing the search unit on the clad surface of the calibration block and manipulating the search unit for the maximum response from the calibration hole. The gain control shall be

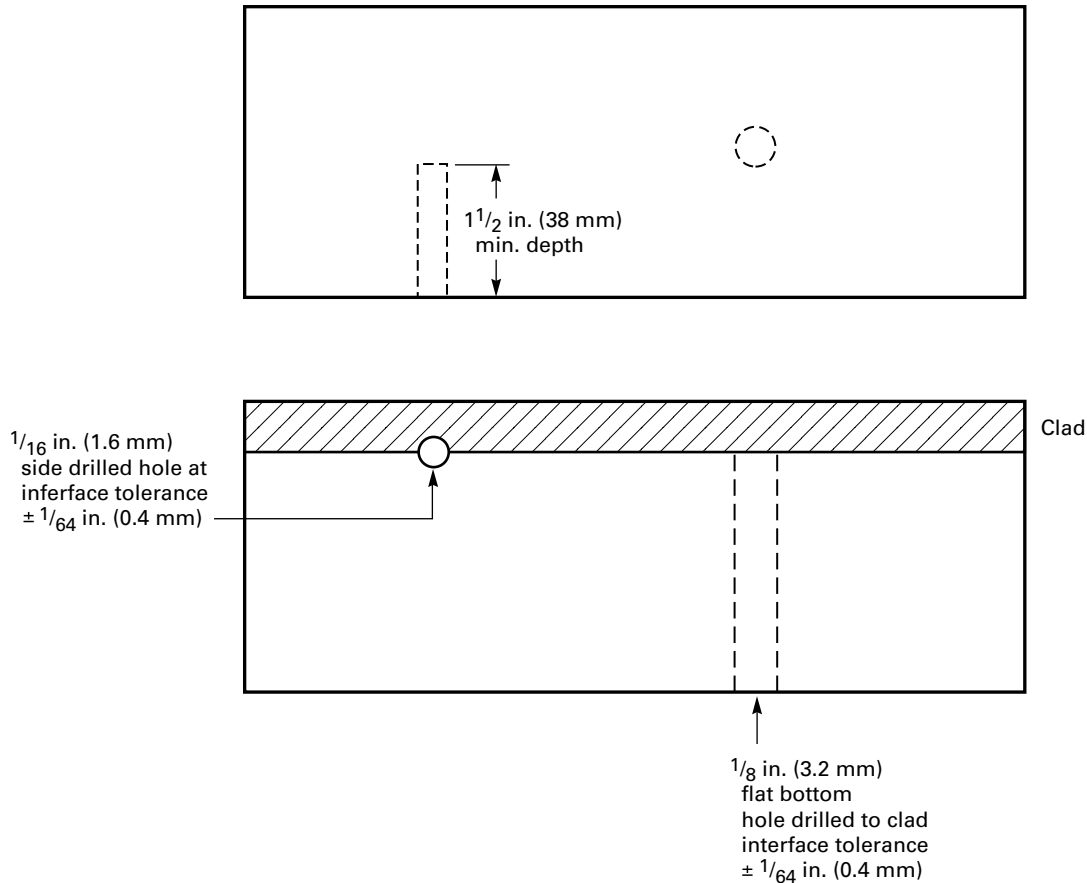


FIG. T-543.2 CALIBRATION BLOCK FOR TECHNIQUE ONE

set so that this response is 80% $\pm$ 5% of full screen. This is primary reference level.

T-543.2.2 Calibration for Technique Two. Calibration shall be accomplished by placing the search unit on the calibration block on the side opposite from which the hole was drilled. The search unit shall be manipulated for the maximum response of the first resolvable indication from the bottom of the calibration hole. The gain shall be set so that this response is 80% $\pm$ 5% of full screen. This shall be the primary reference level.

T-543.3 Examination

T-543.3.1 Technique One

(a) *Examination Area.* The entire clad surface shall be examined where practical. The examination shall be performed with the plane separating the elements of the dual search unit parallel to the axis of the weld bead. Examination shall be performed from the clad surface.

(b) *Scanning Sensitivity.* Scanning shall be performed at the primary reference level.

(c) *Evaluation.* All indications shall be evaluated at the primary reference level.

(d) *Scanning Direction.* The clad surface shall be scanned by moving the search unit perpendicular to the weld direction.

T-543.3.2 Technique Two

(a) *Examination Area.* As required by the referencing Code Section.

(b) *Scanning Sensitivity.* Scanning shall be performed at a gain higher than the primary reference level.

(c) Scanning shall be performed on the clad surface when calibration is performed on the clad surface. Scanning shall be performed on the unclad surface when calibration is performed on the unclad surface.

(d) *Evaluation.* All indications shall be evaluated at the primary reference level.

01 T-544 Thickness Measurement

Procedures used for ultrasonic examination for thickness determination shall conform to the following standards in Article 23, as applicable:

(a) SE-114 Standard Practice for Ultrasonic Pulse-Echo Straight-Beam Examination by the Contact Method

(b) SE-797 Standard Practice for Measuring Thickness by Manual Contact Ultrasonic Method

T-544.1 Equipment. The requirements for equipment shall be in accordance with T-530, and supplemented as follows:

(a) Frequency-thickness measurements may be conducted at any frequency capable of resolving the thickness range to be measured.

(b) The thickness measurement shall be indicated by a cathode ray tube, meter, or digital display.

(c) Calibration block(s) of similar ultrasonic velocity, surface, shape, and finish shall be provided.

NOTE: Common practice for obtaining similar ultrasonic velocities is to use similar material and product form (either wrought or cast).

T-544.2 Calibration. The examination system shall be calibrated on at least 2, preferably 3, calibration thicknesses covering the thickness range to be measured. Measurement accuracy, as noted in SE-114, is dependent upon calibration accuracy.

T-544.3 Examination. The technique used will depend on the thickness, surface geometry, and condition of the workpiece, except that the linearity requirements of T-532 and T-533 are not applicable to thickness measurements. The measurement technique used, and the extent of examination, shall comply with the referencing Code Section.

T-580 EVALUATION**T-581 Examination Using DAC**

For examination using a distance-amplitude correction curve (DAC), any reflector which causes an indication in excess of 20% of DAC shall be investigated to the extent that it can be evaluated in terms of the acceptance standards of the referencing Code Section.

T-582 Examination Using Other Than DAC

For examination using other than DAC, evaluate according to the requirements of the referencing Code Section.

T-590 REPORTS AND RECORDS**T-591 Examination Reports**

A report of the examinations shall be made. The report shall include a record indicating the weld(s) or volume examined (this may be marked-up sketched), the location of each recorded reflector, and the identification of the operator who carried out each examination or part thereof as detailed in T-593.

T-592 Calibration Records

Instrument calibrations in accordance with T-530 shall be included in the ultrasonic calibration records. Ultrasonic examination system calibration requirements in accordance with T-534 and calibration block identity shall be included in the ultrasonic calibration records.

T-593 Examination Records

For each ultrasonic examination, the following information should be identified and recorded. The referencing Code Section shall be consulted for specific requirements.

- (a) procedure;
- (b) ultrasonic examination system (equipment);
- (c) examination personnel identity and level;
- (d) calibration sheet identity;
- (e) identification and location of weld or volume scanned;
- (f) surface from which examination is conducted;
- (g) map or record of indications detected or areas clear;
- (h) date and time examinations were performed;
- (i) couplant;
- (j) basic calibration block identification;
- (k) surface condition;
- (l) frequency;
- (m) special equipment.

T-594 Evaluation Record

Records of any evaluations of indications shall be maintained and documented as required by the referencing Code Section.

ARTICLE 5

MANDATORY APPENDICES

APPENDIX I — SCREEN HEIGHT LINEARITY

To verify the ability of the ultrasonic instrument to meet the linearity requirement of T-532, position an angle beam search unit as shown in Fig. I-1 so that indications can be observed from both the $\frac{1}{2}$ and $\frac{3}{4}T$ holes in a basic calibration block. Adjust the search unit position to give a 2:1 ratio of amplitudes between the two indications, with the larger set at 80% of full screen height. Without moving the search unit, adjust sensitivity (gain) to successively set the larger indication from 100% to 20% of full screen height, in 10% increments (or 2 dB steps if a fine control is not available), and read the smaller indication at each setting. The reading must be 50% of the larger amplitude, within 5% of full screen height. The settings and readings must be estimated to the nearest 1% of full screen. Alternatively, a straight beam search unit may be used on any calibration block, which will provide amplitude differences, with sufficient signal separation to prevent overlapping of the two signals.

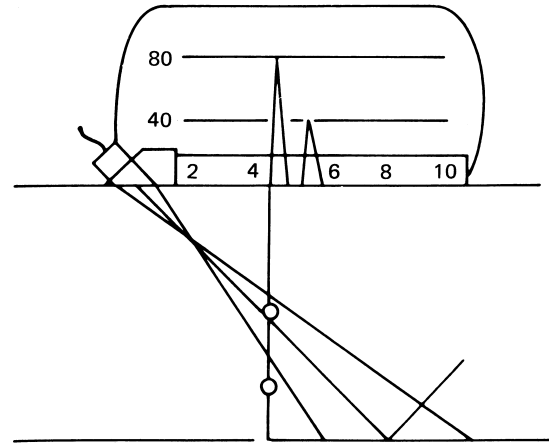


FIG. I-1 LINEARITY

The settings and readings must be estimated to the nearest 1% of full screen.

APPENDIX II — AMPLITUDE CONTROL LINEARITY

To verify the accuracy of the amplitude control of the ultrasonic instrument, as required in T-533, position an angle beam search unit as shown in Fig. I-1 so that the indication from the $\frac{1}{2}T$ hole in a basic calibration block is peaked on the screen. With the increases and decreases in attenuation shown in the following table, the indication must fall within the specified limits. Other convenient reflectors from any calibration block may be used with angle or straight beam search units.

Indication Set at % of Full Screen	dB Control Change	Indication Limits % of Full Screen
80%	-6 dB	32 to 48%
80%	-12 dB	16 to 24%
40%	+6 dB	64 to 96%
20%	+12 dB	64 to 96%

APPENDIX III — GLOSSARY OF TERMS FOR ULTRASONIC EXAMINATION

III-510 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definition of terms related to Ultrasonic Examination.

III-520 GENERAL REQUIREMENTS

01

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 Section I provides the definitions of terms listed in III-530(a).

(c) For general terms, such as *Interpretation*, *Flaw*, *Discontinuity*, *Evaluation*, etc., refer to Article 1, Mandatory Appendix I.

(d) Paragraph III-530(b) provides a list of terms and definitions, which are in addition to SE-1316 and are Code specific.

III-530 REQUIREMENTS

(a) The following SE-1316 terms are used in conjunction with this Article: A-scan; amplitude; angle beam; attenuation; attenuator; B-scan presentation; back reflection; base line; beam axis; beam spread; C-scan; collimator; compressional wave; couplant; critical angle; crystal; damping; search unit; decibel (dB); delayed sweep; Distance Amplitude Correction (DAC) curve; dual search unit; dynamic range; echo; examination system; far field; focused beam; frequency (fundamental); frequency (inspection); frequency (pulse repetition); gate; harmonics; holography (acoustic); immersion testing; impedance (acoustic); indication; initial pulse; interface; lamb wave; linearity (amplitude); linearity (time or distance); longitudinal wave; mode; mode conversion; near field; noise; normal incidence; plate wave; probe; pulse; pulse echo method; pulse length; pulse repetition rate; pulse tuning; radio frequency (RF) display; range; Rayleigh wave; reference block; reflector; reject; resolution; resonance method; saturation; scanning; scattered energy; scattering; Schlieren system; search unit; sensitivity; shadow; shear wave; signal-to-noise ratio; straight beam; sweep; test surface; through transmission technique; transducer; transverse wave; ultrasonic; ultrasonic response; ultrasonic spectroscopy; vee path; video presentation; water path; wave front; wave train; wedge.

(b) The following Code terms are used in conjunction with this Article:

axial direction — direction of sound beam parallel to component's major axis

calibration — correlation of the ultrasonic system response(s) with calibration reflector(s)

calibration reflector — a reflector with a dimensioned surface which is used to provide an accurately reproducible reference level

circumferential direction — direction of sound beam perpendicular to (cylindrical) component's major axis

clipping — see *reject*

computerized imaging — computer processed display or analysis and display of ultrasonic data to provide two- or three-dimensional images of reflectors

crack-tip diffraction — the edge wave emanating from a flaw that is insonified by an ultrasonic beam

CRT — cathode ray tube

dynamic calibration — calibration that is conducted with the search unit in motion, usually at the same speed and direction of the actual test examination

electric simulator — an electronic device that enables correlation of ultrasonic system response initially obtained employing the basic calibration block

image space — a computer selected volume of material being interrogated by the ultrasonic field

multiple back reflections — in ultrasonic straight beam examination, successive reflections between back and front surfaces of the material

oscillogram — common term for photograph of data displayed on CRT

piezoelectric element — crystal or polycrystal materials which when mechanically deformed, produce electrical charges, and conversely, when intermittently charged, will deform and produce mechanical vibrations

primary reference response (level) — the ultrasonic response from the basic calibration reflector at the specified sound path distance, electronically adjusted to a specified percentage of the full screen height

refraction — the angular change in direction of the ultrasonic beam as it passes obliquely from one medium to another, in which the waves have a different velocity

ringing time — the time that the mechanical vibrations of a piezoelectric element continue after the electrical pulse has stopped

simulation block — a reference block or other item in addition to the basic calibration block that enables correlation of ultrasonic system response initially obtained when using the basic calibration block

SAFT-UT — Synthetic Aperture Focusing Technique for ultrasonic testing

static calibration — calibration for examination wherein the search unit is positioned on a calibration block so that the pertinent reflectors can be identified and the instrumentation adjusted accordingly

time-of-flight — the time required for an ultrasonic pulse to travel from the transmitter to the receiver

ARTICLE 5

NONMANDATORY APPENDIX

APPENDIX A — ALTERNATE CALIBRATION BLOCK CONFIGURATION

Flat basic calibration blocks of various thicknesses may also be used to calibrate the examination of convex surface materials greater than 20 in. (508 mm) in diameter. An adjustment of receiver gain may be required when flat calibration blocks are used. The gain corrections apply to the far field portion of the sound beam.

A-10 DETERMINATION OF GAIN CORRECTION

To determine the required increase in gain, the ratio of the material radius, R , to the critical radius of the transducer, R_c , must be evaluated as follows.

(a) When the ratio of R/R_c , the radius of curvature of the material R divided by the critical radius of the transducer R_c from Table A-10 and Fig. A-10(a), is equal to or greater than 1.0, no gain correction is required.

(b) When the ratio of R/R_c is less than 1.0, the gain correction must be obtained from Fig. A-10(b).

(c) *Example.* Material with a 10 in. (254 mm) radius (R) will be examined with a 1 in. (25 mm) diameter 2.25 MHz boron carbide faced search unit using glycerine as a couplant.

(1) Determine the appropriate transducer factor, F_1 from Table A-10; $F_1 = 93$.

TABLE A-10
TRANSDUCER FACTOR F_1 FOR VARIOUS
ULTRASONIC TRANSDUCER
DIAMETERS AND FREQUENCIES

U.S. Customary Units					
Frequency MHz	Transducer Diameters, in.				
	0.25	0.5	0.75	1.0	1.125
	F_1 , in.				
1.0	2.58	10.3	23.2	41.3	52.3
2.25	5.81	23.2	52.2	92.9	118
5.0	12.9	51.2	116	207	262
10.0	25.8	103	232	413	523
SI Units					
Frequency MHz	Transducer Diameters, mm				
	6.4	13	19	25	29
	F_1 , mm				
1.0	66	262	589	1 049	1 328
2.25	148	589	1 326	2 360	2 997
5.0	328	1 300	2 946	5 258	6 655
10.0	655	2 616	5 893	10 490	13 284

(2) Determine the R_c from Fig. A-10(a); $R_c = 100$ in.

(3) Calculate the R/R_c ratio; 10 in./100 in. (25 mm/254 mm) = 0.1.

(4) Using Fig. A-10(b), obtain the gain increase required; 12 dB.

This gain increase calibrates the examination on the curved surface after establishing calibration sensitivity on a flat calibration block.

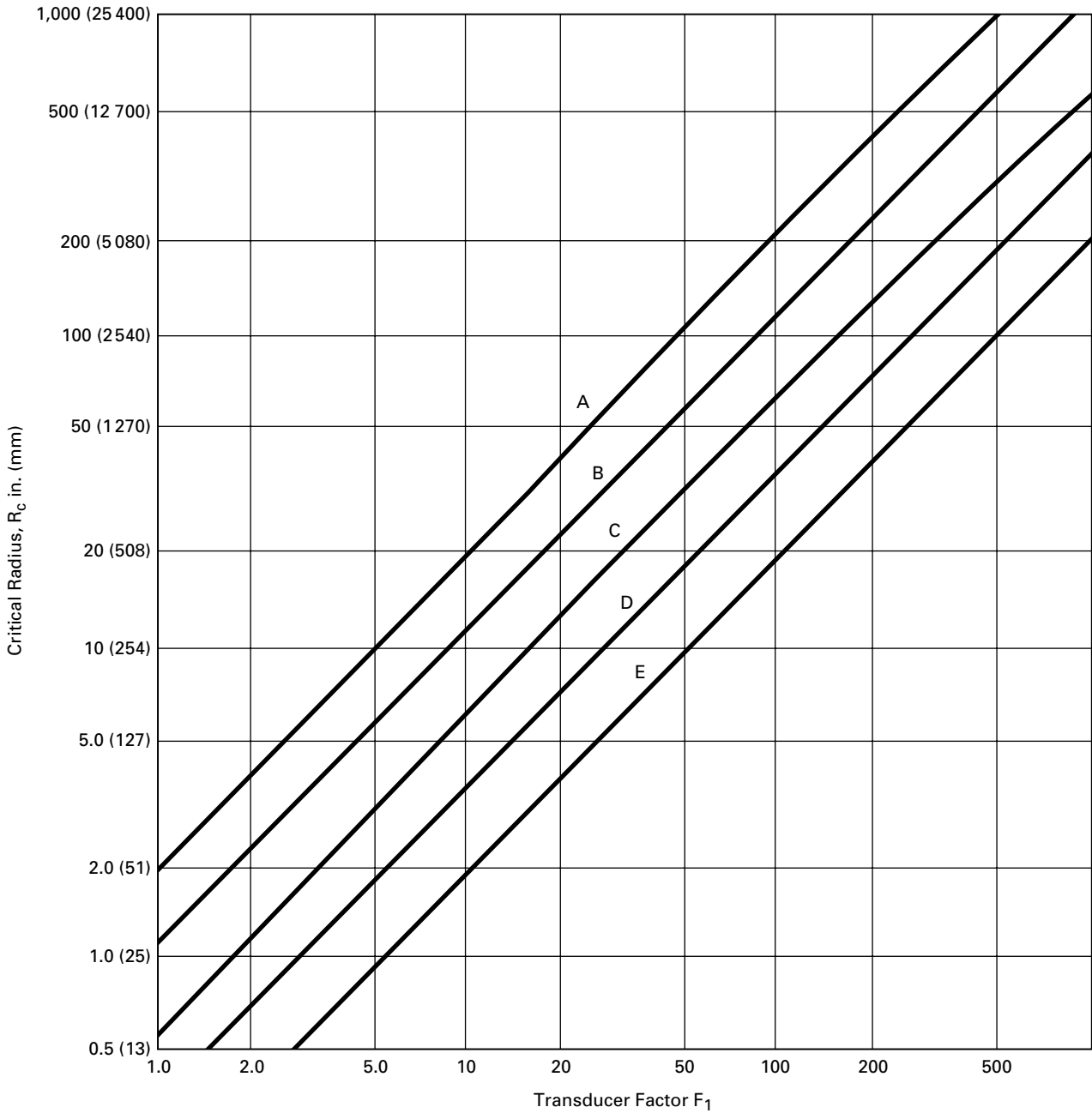


FIG. A-10(a) CRITICAL RADIUS R_c FOR TRANSDUCER/COUPLANT COMBINATIONS

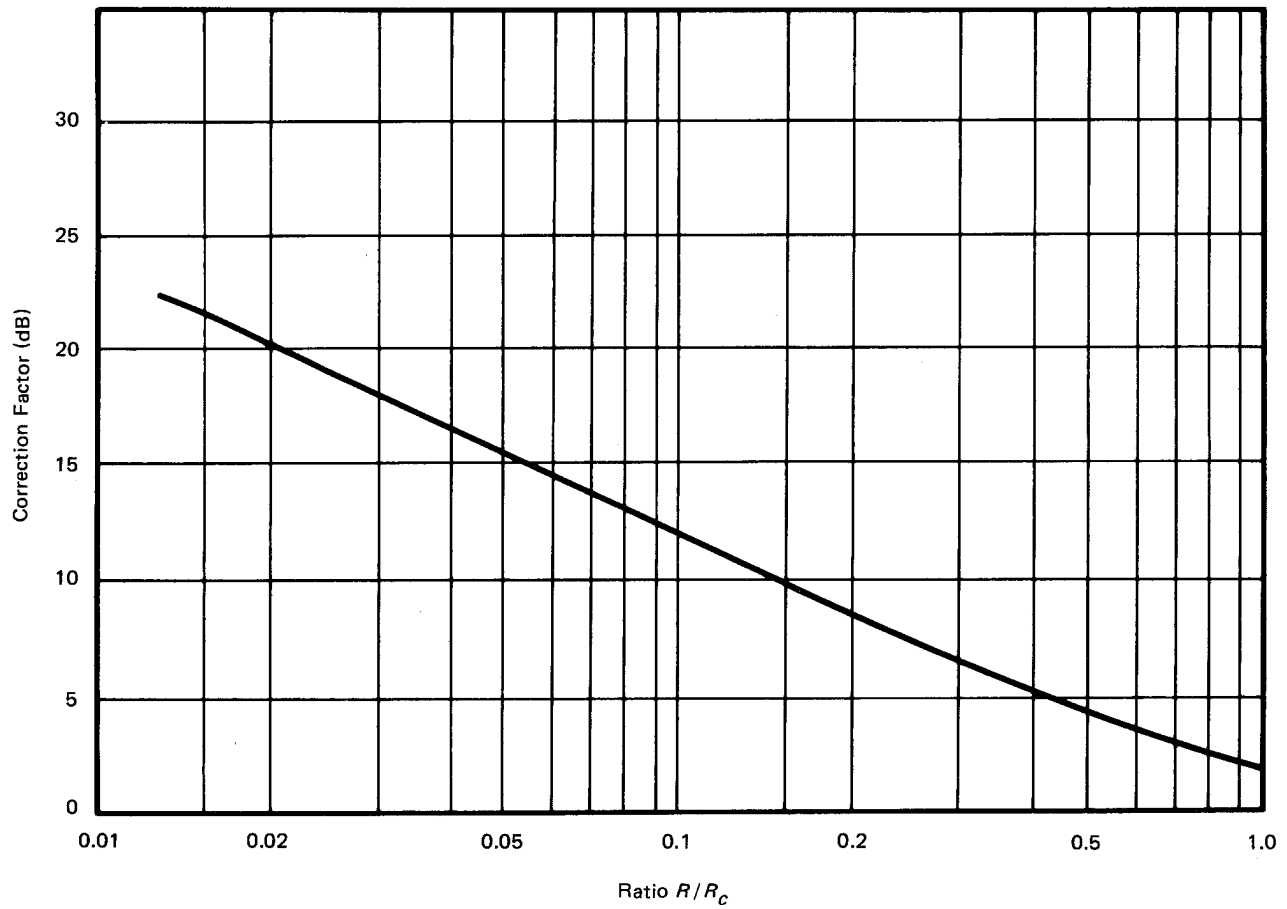


FIG. A-10(b) CORRECTION FACTOR (GAIN) FOR VARIOUS ULTRASONIC EXAMINATION PARAMETERS

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ARTICLE 6

LIQUID PENETRANT EXAMINATION

T-600 SCOPE

The liquid penetrant examination method is an effective means for detecting discontinuities which are open to the surface of nonporous metals and other materials. Typical discontinuities detectable by this method are cracks, seams, laps, cold shuts, laminations, and porosity.

In principle, a liquid penetrant is applied to the surface to be examined and allowed to enter discontinuities. All excess penetrant is then removed, the part is dried, and a developer is applied. The developer functions both as a blotter to absorb penetrant that has been trapped in discontinuities, and as a contrasting background to enhance the visibility of penetrant indications. The dyes in penetrants are either color contrast (visible under white light) or fluorescent (visible under ultraviolet light).

T-610 REFERENCING DOCUMENTS

01 **T-610.1** When specified by the referencing Code Section, the liquid penetrant examination techniques described in this Article shall be used. The following SE Standard provides details that may be considered in the specific procedures used:

(a) SE-165 Standard Test Method for Liquid Penetrant Examination

T-610.2 The liquid penetrant method described in this Article shall be used together with Article 1, General Requirements.

T-610.3 Definitions of terms used in this Article are in Mandatory Appendix I of this Article.

T-620 GENERAL

01 T-621 Procedure Requirements

01 **T-621.1** Liquid penetrant examination shall be performed in accordance with a written procedure. Each

procedure shall include at least the following information, as applicable:

(a) the materials, shapes, or sizes to be examined, and the extent of the examination;

(b) type (number or letter designation if available) of each penetrant, penetrant remover, emulsifier, and developer;

(c) processing details for pre-examination cleaning and drying, including the cleaning materials used and minimum time allowed for drying;

(d) processing details for applying the penetrant: the length of time that the penetrant will remain on the surface (dwell time), and the temperature of the surface and penetrant during the examination if outside 50°F (10°C) to 125°F (52°C) range;

(e) processing details for removing excess penetrant from the surface, and for drying the surface before applying the developer;

(f) processing details for applying the developer, and length of developing time before interpretation;

(g) processing details for post-examination cleaning.

T-621.2 Procedure Revision. A revised procedure may be required:

(a) whenever a change or substitution is made in the type or family group of penetrant materials (including developers, emulsifiers, etc.) or in the processing techniques;

(b) whenever a change or substitution is made in the type of precleaning materials or processes;

(c) for any change in part processing that can close surface openings of discontinuities or leave interfering deposits, such as the use of grit blast cleaning or acid treatments.

T-630 EQUIPMENT

T-631 Penetrant Materials

The term *penetrant materials*, as used in this Article, is intended to include all penetrants, emulsifiers, solvents or cleaning agents, developers, etc., used in the examina-

tion process. The descriptions of the liquid penetrant classifications and material types are provided in SE-165.

T-640 REQUIREMENTS

T-641 Control of Contaminants

The user of this Article shall obtain certification of contaminant content for all liquid penetrant materials used on nickel base alloys, austenitic stainless steels, and titanium. These certifications shall include the penetrant manufacturers' batch numbers and the test results obtained in accordance with (a) and (b) below. These records shall be maintained as required by the referencing Code Section.

(a) When examining nickel base alloys, all materials shall be analyzed individually for sulfur content as follows.

(1) An individual sample of the penetrant materials with exception of cleaners shall be prepared for analysis by heating 50 g of the material in a 150 mm nominal diameter glass Petri dish at a temperature of 194°F to 212°F (90°C to 100°C) for 60 min.

PRECAUTION: Provide adequate ventilation to dissipate the emitted vapor.

(2) Analysis of the residue shall be as follows: If the residue is less than 0.0025 g, the material is acceptable without further analysis. If the residue is 0.0025 g or more, the procedure shown in (a)(1) above shall be repeated and the residue analyzed in accordance with SD-129 or SD-1552. Alternately, the material may be decomposed in accordance with SD-129 and analyzed in accordance with SD-516 Method B. The sulphur content shall not exceed 1% of the residue by weight.

(3) An individual sample of cleaner/remover material shall be prepared for analysis by heating 100 g of the material in a 150 mm nominal diameter glass Petri dish at a temperature of 194°F to 212°F (90°C to 100°C) for 60 min.

PRECAUTION: Provide adequate ventilation to dissipate the emitted vapor.

(4) Analysis of the residue shall be as follows: If the residue is less than 0.005 g, the material is acceptable without further analysis. If the residue is 0.005 g or more, the procedure shown in (a)(3) above shall be repeated and the residue analyzed in accordance with SD-129 or SD-1552. Alternately the material may be decomposed in accordance with SD-129 and analyzed in accordance with SD-516 Method B. The sulphur content shall not exceed 1% of the residue by weight.

(b) When examining austenitic stainless steel or titanium, all materials shall be analyzed individually for chlorine and fluorine content as follows.

(1) An individual sample of the penetrant materials with the exception of cleaners shall be prepared for analysis by heating 50 g of the material in a 150 mm nominal diameter glass Petri dish at a temperature of 194°F to 212°F (90°C to 100°C) for 60 min.

PRECAUTION: Provide adequate ventilation to dissipate the emitted vapor.

(2) If the residue is 0.0025 g or more, the procedure shown in (b)(1) above shall be repeated. The residue may be analyzed in accordance with SD-808 and the total shall not exceed 1% by weight. Or, alternately, the residue shall be analyzed in accordance with SE-165, Annex 2 for chlorine and SE-165, Annex 3 for fluorine, and the total chlorine plus fluorine content shall not exceed 1% by weight.

(3) An individual sample of the cleaner/remover material shall be prepared for analysis by heating 100 g of the material in a 150 mm nominal diameter glass Petri dish at a temperature of 194°F to 212°F (90°C to 100°C) for 60 min.

PRECAUTION: Provide adequate ventilation to dissipate the emitted vapor.

(4) If the residue is 0.005 g or more, the procedure shown in (b)(3) above shall be repeated. The residue may be analyzed in accordance with SD-808 and the total shall not exceed 1% by weight. Or, alternately, the residue shall be analyzed in accordance with SE-165, Annex 2 for chlorine and SE-165, Annex 3 for fluorine, and the total chlorine plus fluorine content shall not exceed 1% by weight.

(c) As an alternative to (a) and (b) above, SE-165, Annex A4 may be used for determination of anions by ion chromatography, which provides a single instrumental technique for rapid sequential measurement of common anions such as chloride, fluoride, and sulfate.

T-642 Surface Preparation

(a) In general, satisfactory results may be obtained when the surface of the part is in the as-welded, as-rolled, as-cast, or as-forged condition. Surface preparation by grinding, machining, or other methods may be necessary where surface irregularities could mask indications of unacceptable discontinuities.

(b) Prior to each liquid penetrant examination, the surface to be examined and all adjacent areas within at least 1 in. (25 mm) shall be dry and free of all dirt, grease, lint, scale, welding flux, weld spatter, paint, oil, and other extraneous matter that could obscure

surface openings or otherwise interfere with the examination.

(c) Typical cleaning agents which may be used are detergents, organic solvents, descaling solutions, and paint removers. Degreasing and ultrasonic cleaning methods may also be used.

(d) Cleaning solvents shall meet the requirements of T-641. The cleaning method employed is an important part of the examination process.

NOTE: Conditioning of surfaces prior to examination may affect the results. See SE-165, Annex A1.

T-643 Drying After Preparation

After cleaning, drying of the surfaces to be examined shall be accomplished by normal evaporation or with forced hot or cold air. A minimum period of time shall be established to ensure that the cleaning solution has evaporated prior to application of the penetrant.

T-650 PROCEDURE/TECHNIQUE

T-651 Techniques

Either a color contrast (visible) penetrant or a fluorescent penetrant shall be used with one of the following three penetrant processes:

- (a) water washable
- (b) post-emulsifying
- (c) solvent removable

The visible and fluorescent penetrants used in combination with these three penetrant processes result in six liquid penetrant techniques.

T-652 Techniques for Standard Temperatures

As a standard technique, the temperature of the penetrant and the surface of the part to be processed shall not be below 50°F (10°C) nor above 125°F (52°C) throughout the examination period. Local heating or cooling is permitted provided the part temperature remains in the range of 50°F to 125°F (10°C to 52°C) during the examination. Where it is not practical to comply with these temperature limitations, other temperatures and times may be used, provided the procedures are qualified as specified in T-653.

T-653 Techniques for Nonstandard Temperatures

T-653.1 General. When it is not practical to conduct a liquid penetrant examination within the temperature range of 50°F to 125°F (10°C to 52°C), the examination procedure at the proposed lower or higher temperature range requires qualification. This shall require the use of a quench cracked aluminum block, which in this Article is designated as a liquid penetrant comparator block.

T-653.2 Liquid Penetrant Comparator. The liquid penetrant comparator blocks shall be made of aluminum, ASTM B 209, Type 2024, $\frac{3}{8}$ in. (10 mm) thick, and should have approximate face dimensions of 2 in. × 3 in. (52 mm × 76 mm). At the center of each face, an area approximately 1 in. (25 mm) in diameter shall be marked with a 950°F (510°C) temperature-indicating crayon or paint. The marked area shall be heated with a blowtorch, a Bunsen burner, or similar device to a temperature between 950°F (510°C) and 975°F (524°C). The specimen shall then be immediately quenched in cold water, which produces a network of fine cracks on each face.

The block shall then be dried by heating to approximately 300°F (149°C). After cooling, the block shall be cut in half. One-half of the specimen shall be designated block "A" and the other block "B" for identification in subsequent processing. Figure T-653.2 illustrates the comparator blocks "A" and "B." As an alternate to cutting the block in half to make blocks "A" and "B," separate blocks 2 in. × 3 in. (52 mm × 76 mm) can be made using the heating and quenching technique as described above. Two comparator blocks with closely matched crack patterns may be used. The blocks shall be marked "A" and "B."

T-653.3 Comparator Application

(a) If it is desired to qualify a liquid penetrant examination procedure at a temperature of less than 50°F (10°C), the proposed procedure shall be applied to block "B" after the block and all materials have been cooled and held at the proposed examination temperature until the comparison is completed. A standard procedure which has previously been demonstrated as suitable for use shall be applied to block "A" in the 50°F to 125°F (10°C to 52°C) temperature range. The indications of cracks shall be compared between blocks "A" and "B." If the indications obtained under the proposed conditions on block "B" are essentially the same as obtained on block "A" during examination at 50°F to 125°F (10°C to 52°C), the proposed procedure shall be considered qualified for use.

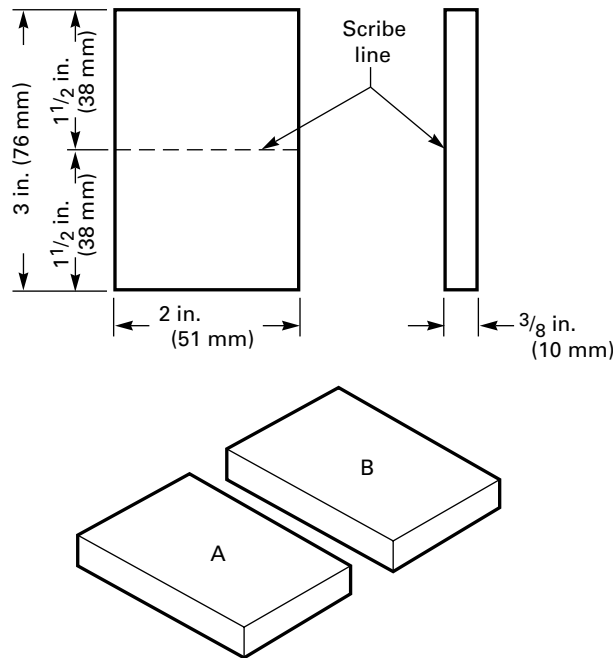


FIG. T-653.2 LIQUID PENETRANT COMPARATOR

(NOTE: Dimensions given are for guidance only and are not critical.)

(b) If the proposed temperature for the examination is above 125°F (52°C), block “B” shall be held at this temperature throughout the examination. The indications of cracks shall be compared as described in T-653.3(a) while block “B” is at the proposed temperature and block “A” is at the 50°F to 125°F (10°C to 52°C) temperature range.

(c) A procedure qualified at a temperature lower than 50°F (10°C) shall be qualified from that temperature to 50°F (10°C).

(d) To qualify a procedure for temperatures above 125°F (52°C), the upper and lower temperature limits shall be established and the procedure qualified at these temperatures.

(e) As an alternate to the requirements of T-653.3(a) and T-653.3(b) when using color contrast penetrants, it is permissible to use a single comparator block for the standard and nonstandard temperatures and to make the comparison by photography.

(1) When the single comparator block and photographic technique is used, the processing details (as applicable) described in T-653.3(a) and T-653.3(b) apply. The block shall be thoroughly cleaned between the two processing steps. Photographs shall be taken after processing at the nonstandard temperature and

then after processing at the standard temperature. The indication of cracks shall be compared between the two photographs. The same criteria for qualification as T-653.3(a) shall apply.

(2) The identical photographic techniques shall be used to make the comparison photographs.

T-654 Technique Restrictions

Fluorescent penetrant examination shall not follow a color contrast penetrant examination. Intermixing of penetrant materials from different families or different manufacturers is not permitted. A retest with water washable penetrants may cause loss of marginal indications due to contamination.

T-670 EXAMINATION

T-671 Penetrant Application

The penetrant may be applied by any suitable means, such as dipping, brushing, or spraying. If the penetrant is applied by spraying using compressed-air-type apparatus, filters shall be placed on the upstream side near the air inlet to preclude contamination of the penetrant by oil, water, dirt, or sediment that may have collected in the lines.

T-672 Penetration Time

Penetration time is critical. The minimum penetration time shall be as required in Table T-672 or as qualified by demonstration for specific applications.

T-673 Excess Penetrant Removal

After the specified penetration time has elapsed, any penetrant remaining on the surface shall be removed, taking care to minimize removal of penetrant from discontinuities.

T-673.1 Water-Washable Penetrants. Excess water-washable penetrant shall be removed with a water spray. The water pressure shall not exceed 50 psi (345 kPa), and the water temperature shall not exceed 110°F (43°C).

T-673.2 Postemulsification Penetrants

(a) *Lipophilic Emulsification.* After the required penetrant dwell time, the excess surface penetrant shall be emulsified by immersing or flooding the part with the emulsifier. Emulsification time is dependent on the type of emulsifier and surface condition. The actual

emulsification time shall be determined experimentally. After emulsification, the mixture shall be removed by immersing in or rinsing with water. The temperature and pressure of the water shall be as recommended by the manufacturer.

(b) *Hydrophilic Emulsification.* After the required penetrant dwell time and prior to emulsification, the parts shall be prerinsed with water spray using the same process as for water-washable penetrants. Prerinsing time shall not exceed 1 min. After prerinsing, the excess surface penetrant shall be emulsified by immersing in or spraying with hydrophilic emulsifier. Bath concentration shall be as recommended by the manufacturer. After emulsification, the mixture shall be removed by immersing in or rinsing with water. The temperature and pressure of the water shall be as recommended by the manufacturer.

NOTE: Additional information may be obtained from SE-165.

T-673.3 Solvent Removable Penetrants. Excess solvent removable penetrants shall be removed by wiping with a cloth or absorbent paper, repeating the operation until most traces of penetrant have been removed. The remaining traces shall be removed by lightly wiping the surface with cloth or absorbent paper moistened with solvent. To minimize removal of penetrant from discontinuities, care shall be taken to avoid the use of excess solvent. **Flushing the surface with solvent, following the application of the penetrant and prior to developing, is prohibited.**

T-674 **Drying After Excess Penetrant Removal**

(a) For the water washable or post-emulsifying technique, the surfaces may be dried by blotting with clean materials or by using circulating air, provided the temperature of the surface is not raised above 125°F (52°C).

(b) For the solvent removable technique, the surfaces may be dried by normal evaporation, blotting, wiping, or forced air.

T-675 **Developing**

The developer shall be applied as soon as possible after penetrant removal; the time interval shall not exceed that established in the procedure. Insufficient coating thickness may not draw the penetrant out of discontinuities; conversely, excessive coating thickness may mask indications.

With color contrast penetrants, only a wet developer shall be used. With fluorescent penetrants, a wet or dry developer may be used.

T-675.1 Dry Developer Application. Dry developer shall be applied only to a dry surface by a soft brush, hand powder bulb, powder gun, or other means, provided the powder is dusted evenly over the entire surface being examined.

T-675.2 Wet Developer Application. Prior to applying suspension type wet developer to the surface, the developer must be thoroughly agitated to ensure adequate dispersion of suspended particles.

(a) *Aqueous Developer Application.* Aqueous developer may be applied to either a wet or dry surface. It shall be applied by dipping, brushing, spraying, or other means, provided a thin coating is obtained over the entire surface being examined. Drying time may be decreased by using warm air, provided the surface temperature of the part is not raised above 125°F. Blotting is not permitted.

(b) *Nonaqueous Developer Application.* Nonaqueous developer shall be applied only to a dry surface. It shall be applied by spraying, except where safety or restricted access preclude it. Under such conditions, developer may be applied by brushing. Drying shall be by normal evaporation.

T-675.3 Developing time for final interpretation begins immediately after the application of a dry developer or as soon as a wet developer coating is dry. The minimum developing time shall be as required by Table T-672.

T-676 **Interpretation**

T-676.1 Final Interpretation. Final interpretation shall be made within 7 to 60 min after the requirements of T-675.3 are satisfied. If bleed-out does not alter the examination results, longer periods are permitted. If the surface to be examined is large enough to preclude complete examination within the prescribed or established time, the examination shall be performed in increments.

T-676.2 Characterizing Indication(s). The type of discontinuities are difficult to evaluate if the penetrant diffuses excessively into the developer. If this condition occurs, close observation of the formation of indication(s) during application of the developer may assist in characterizing and determining the extent of the indication(s).

TABLE T-672 MINIMUM DWELL TIMES

Material	Form	Type of Discontinuity	Dwell Times [Note (1)] (minutes)	
			Penetrant	Developer
Aluminum, magnesium, steel, brass and bronze, titanium and high- temperature alloys	Castings and welds	Cold shuts, porosity, lack of fusion, cracks (all forms)	5	7
	Wrought materials — extrusions, forgings, plate	Laps, cracks (all forms)	10	7
Carbide-tipped tools		Lack of fusion, porosity, cracks	5	7
Plastic	All forms	Cracks	5	7
Glass	All forms	Cracks	5	7
Ceramic	All forms	Cracks, porosity	5	7

NOTE:

(1) For temperature range from 50°F to 125°F (10°C to 52°C).

T-676.3 Color Contrast Penetrants. With a color contrast penetrant, the developer forms a reasonably uniform white coating. Surface discontinuities are indicated by bleed-out of the penetrant which is normally a deep red color that stains the developer. Indications with a light pink color may indicate excessive cleaning. Inadequate cleaning may leave an excessive background making interpretation difficult. A minimum light intensity of 50 fc (500 Lx) is required to ensure adequate sensitivity during the examination and evaluation of indications.

T-676.4 Fluorescent Penetrants. With fluorescent penetrants, the process is essentially the same as in T-676.3, with the exception that the examination is performed using an ultraviolet light, called *black light*. The examination shall be performed as follows:

- (a) It shall be performed in a darkened area.
- (b) The examiner shall be in the darkened area for at least 1 min prior to performing the examination to enable his eyes to adapt to dark viewing. If the examiner wears glasses or lenses, they shall not be photosensitive.
- (c) The black light shall be allowed to warm up for a minimum of 5 min prior to use or measurement of the intensity of the ultraviolet light emitted.
- (d) The black light intensity shall be measured with a black light meter. A minimum of 1000 $\mu\text{W}/\text{cm}^2$ on the surface of the part being examined shall be required.

The black light intensity shall be measured at least once every 8 hr, and whenever the work station is changed.

T-677 Post-examination Cleaning

When post-examination cleaning is required by the procedure, it should be conducted as soon as practical using a process that does not adversely affect the part.

T-680 EVALUATION

(a) All indications shall be evaluated in terms of the acceptance standards of the referencing Code Section.

(b) Discontinuities at the surface will be indicated by bleed-out of penetrant; however, localized surface irregularities due to machining marks or other surface conditions may produce false indications.

(c) Broad areas of fluorescence or pigmentation which could mask indications of discontinuities are unacceptable, and such areas shall be cleaned and reexamined.

T-690 DOCUMENTATION/RECORDS

T-690.1 Documentation/records shall be in accordance with the referencing Code Section.

ARTICLE 6

MANDATORY APPENDIX

APPENDIX I — GLOSSARY OF TERMS FOR LIQUID PENETRANT EXAMINATION

I-610 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definition of terms which appear in Article 6, Liquid Penetrant Examination.

I-620 GENERAL REQUIREMENTS

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 Section G provides the definitions of terms listed in I-630(a).

(c) For general terms, such as *Indication*, *Flaw*, *Discontinuity*, *Evaluation*, etc., refer to Article 1, Mandatory Appendix 1.

(d) Paragraph I-630(b) provides a list of terms and definitions, which are in addition to SE-1316 and are Code specific.

I-630 REQUIREMENTS

(a) The following SE-1316 terms are used in conjunction with this Article: black light; bleedout; blotting; clean; contaminant; contrast; developer; developer, aqueous; developer, dry; developer, nonaqueous; developing time; drying time; dwell time; emulsifier; family; fluorescence; overemulsification; penetrant; penetrant comparator; penetrant fluorescent; penetrant, water washable; post-cleaning; post emulsification; precleaning; rinse; solvent remover.

(b) The following Code terms are used in conjunction with this Article:

black light intensity — a quantitative expression of ultraviolet irradiance

color contrast penetrant — a highly penetrating liquid incorporating a nonfluorescent dye, which produces indications of such intensity that they are readily visible during examination under white light

post emulsification penetrant — a type of penetrant containing no emulsifier, but which requires a separate emulsifying step to facilitate water rinse removal of the surface penetrant

solvent removable penetrant — a type of penetrant used where the excess penetrant is removed from the surface of the part by wiping using a nonaqueous liquid

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ARTICLE 7

MAGNETIC PARTICLE EXAMINATION

T-710 SCOPE

When specified by the referencing Code Section, the magnetic particle examination techniques described in this Article shall be used. In general, this Article is in conformance with SE-709, Standard Guide for Magnetic Particle Examination. This document provides details to be considered in the procedures used.

When this Article is specified by a referencing Code Section, the magnetic particle method described in this Article shall be used together with Article 1, General Requirements. Definition of terms used in this Article are in Mandatory Appendix II.

T-720 GENERAL

The magnetic particle examination method may be applied to detect cracks and other discontinuities on or near the surfaces of ferromagnetic materials. The sensitivity is greatest for surface discontinuities and diminishes rapidly with increasing depth of subsurface discontinuities below the surface. Typical types of discontinuities that can be detected by this method are cracks, laps, seams, cold shuts, and laminations.

In principle, this method involves magnetizing an area to be examined, and applying ferromagnetic particles (the examination medium) to the surface. The particles will form patterns on the surface where cracks and other discontinuities cause distortions in the normal magnetic field. These patterns are usually characteristic of the type of discontinuity that is detected.

Whichever technique is used to produce the magnetic flux in the part, maximum sensitivity will be to linear discontinuities oriented perpendicular to the lines of flux. For optimum effectiveness in detecting all types of discontinuities, each area should be examined at least twice, with the lines of flux during one examination approximately perpendicular to the lines of flux during the other.

T-730 EQUIPMENT

A suitable and appropriate means for producing the necessary magnetic flux in the part shall be employed, using one or more of the techniques listed in T-752 and described in T-770.

T-731 Examination Medium

The finely divided ferromagnetic particles used for the examination shall meet the following requirements.

(a) *Particle Types.* The particles shall be treated to impart color (fluorescent pigments, nonfluorescent pigments, or both) in order to make them highly visible (contrasting) against the background of the surface being examined.

(b) *Particles.* Dry and wet particles, including wet particle suspension vehicles, and particle concentrations shall be in accordance with SE-709.

(c) *Temperature Limitations.* Particles shall be used within the temperature range limitations set by the manufacturer. Alternatively, particles may be used outside the manufacturer's recommendations providing the procedure is qualified in accordance with Article 1, T-150.

T-740 REQUIREMENTS

T-741 Surface Conditioning

T-741.1 Preparation

(a) Satisfactory results are usually obtained when the surfaces are in the as-welded, as-rolled, as-cast, or as-forged conditions. However, surface preparation by grinding or machining may be necessary where surface irregularities could mask indications due to discontinuities.

(b) Prior to magnetic particle examination, the surface to be examined and all adjacent areas within at least 1 in. (25 mm) shall be dry and free of all dirt, grease, lint, scale, welding flux and spatter, oil, or

other extraneous matter that could interfere with the examination.

(c) Cleaning may be accomplished using detergents, organic solvents, descaling solutions, paint removers, vapor degreasing, sand or grit blasting, or ultrasonic cleaning methods.

(d) If coatings are left on the part in the area being examined, it must be demonstrated that indications can be detected through the existing maximum coating thickness applied. When AC yoke technique is used, the demonstration must be in accordance with Mandatory Appendix I of this Article.

T-741.2 Surface Contrast Enhancement. When coatings are applied temporarily to uncoated surfaces only in amounts sufficient to enhance particle contrast, it must be demonstrated that indications can be detected through the enhancement coating.

NOTE: Refer to T-150(a) for guidance for the demonstration required in T-741.1(d) and T-741.2.

01 T-750 PROCEDURE REQUIREMENTS

Magnetic particle examination shall be performed in accordance with a written procedure.

Each procedure shall include at least the following information, as applicable:

- (a) the materials, shapes, or sizes to be examined, and the extent of the examination;
- (b) magnetization techniques to be used;
- (c) equipment to be used for magnetization;
- (d) surface preparation (finishing and cleaning);
- (e) type of ferromagnetic particles to be used: manufacturer, color, wet or dry, etc.;
- (f) maximum allowable temperature for ferromagnetic particles to be used: per manufacturer recommendation or by qualification;
- (g) magnetization currents (type and amperage);
- (h) demagnetization;
- (i) post-examination cleaning.

T-751 Method of Examination

Examination shall be done by the continuous method; that is, the magnetizing current remains on while the examination medium is being applied and while excess of the examination medium is being removed.

T-752 Techniques and Materials

The ferromagnetic particles used as an examination medium shall be either wet or dry, and may be either fluorescent or nonfluorescent.

One or more of the following five magnetization techniques shall be used:

- (a) prod technique;
- (b) longitudinal magnetization technique;
- (c) circular magnetization technique;
- (d) yoke technique;
- (e) multidirectional magnetization technique.

T-753 Magnetizing Field Adequacy and Direction

T-753.1 Magnetic Field Adequacy. The applied magnetic field shall have sufficient strength to produce satisfactory indications, but it shall not be so strong that it causes the masking of relevant indications by nonrelevant accumulations of magnetic particles. Factors that influence the required field strength include the size, shape, and material permeability of the part; the technique of magnetization; coatings; the method of particle application; and the type and location of discontinuities to be detected. When it is necessary to verify the adequacy of magnetic field strength, it shall be verified by using one or more of the following three methods.

T-753.1.1 Pie-Shaped Magnetic Particle Field Indicator. The indicator, shown in Fig. T-753.1.1, shall be positioned on the surface to be examined, such that the copper-plated side is away from the inspected surface. A suitable field strength is indicated when a clearly defined line (or lines) of magnetic particles form(s) across the copper face of the indicator when the magnetic particles are applied simultaneously with the magnetizing force. When a clearly defined line of particles is not formed, the magnetizing technique shall be changed as needed. Pie-type indicators are best used with dry particle procedures.

T-753.1.2 Artificial Flaw Shims. The shim, shown in Fig. T-753.1.2, shall be attached to the surface to be examined, such that the artificial flaw side of the shim is toward the inspected surface. A suitable field strength is indicated when a clearly defined line (or lines) of magnetic particles, representing the 30% depth flaw, appear(s) on the shim face when magnetic particles are applied simultaneously with the magnetizing force. When a clearly defined line of particles is not formed, the magnetizing technique shall be changed as needed.

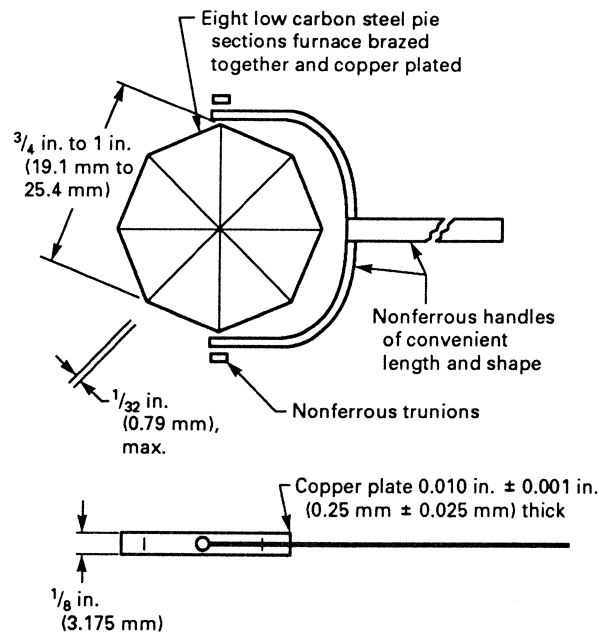


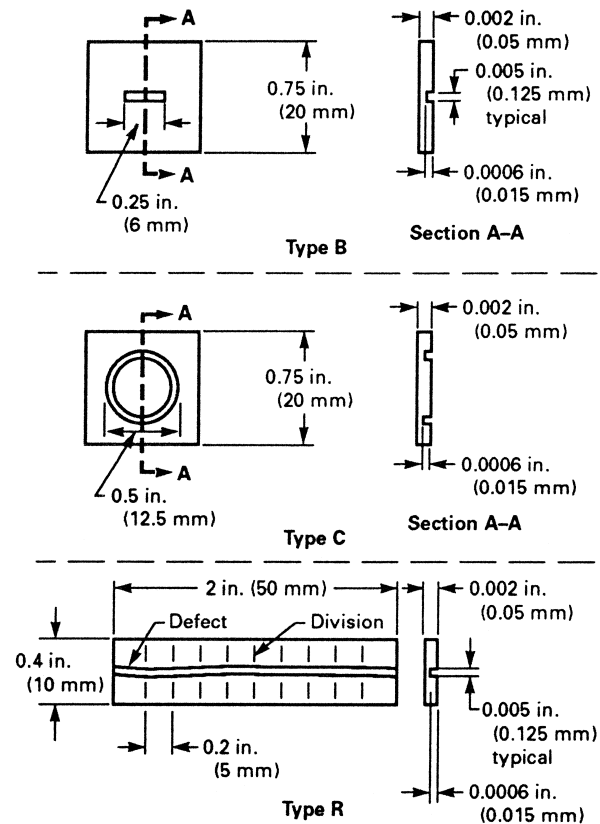
FIG. T-753.1.1 PIE-SHAPED MAGNETIC PARTICLE FIELD INDICATOR

Shim-type indicators are best used with wet particle procedures.

T-753.1.3 Hall-Effect Tangential-Field Probe. A gaussmeter and Hall-Effect tangential-field probe shall be used for measuring the peak value of a tangential field. The probe shall be positioned on the surface to be examined, such that the maximum field strength is determined. A suitable field strength is indicated when the measured field is within the range of 30 G to 60 G (2.4 kAm^{-1} to 4.8 kAm^{-1}) while the magnetizing force is being applied. See Article 7, Nonmandatory Appendix A.

T-753.2 Magnetic Field Direction. The direction of magnetization shall be determined by particle indications obtained using an indicator or shims as shown in Fig. T-753.1.1 or Fig. T-753.1.2. When a clearly defined line of particles is not formed in the desired direction, the magnetizing technique shall be changed as needed.

T-753.2.1 For multidirectional magnetization techniques, the orientation of the lines of flux shall be in at least two nearly perpendicular directions. When clearly defined lines of particles are not formed in at least two nearly perpendicular directions, the magnetizing technique shall be changed as needed.



GENERAL NOTE:

Above are examples of artificial flaw shims used in magnetic particle inspection system verification (not drawn to scale). The shims are made of low carbon steel (1005 steel foil). The artificial flaw is etched or machined on one side of the foil to a depth of 30% of the foil thickness.

FIG. T-753.1.2 ARTIFICIAL FLAW SHIMS

T-753.3 Determination of the adequacy and direction of magnetizing fields using magnetic field indicators or artificial flaws are only permitted when specifically referenced by the magnetizing technique in T-774.2(c), T-774.2(d), T-775.1(b)(3), T-775.2(a), T-775.2(b), and T-777.2.

T-754 Rectified Current

(a) Whenever direct current is required rectified current may be used. The rectified current for magnetization shall be either three-phase (full-wave rectified) current, or single phase (half-wave rectified) current.

(b) The amperage required with three-phase, full-wave rectified current shall be verified by measuring the average current.

(c) The amperage required with single-phase (half-wave rectified) current shall be verified by measuring the average current output during the conducting half cycle only.

(d) When measuring half-wave rectified current with a direct current test meter, readings shall be multiplied by two.

T-755 Demagnetization

When residual magnetism in the part could interfere with subsequent processing or usage, the part shall be demagnetized any time after completion of the examination.

T-756 Post-examination Cleaning

When postexamination cleaning is required by the procedure, it should be conducted as soon as practical using a process that does not adversely affect the part.

T-760 CALIBRATION OF EQUIPMENT

T-761 Frequency of Calibration

(a) *Frequency.* Each piece of magnetizing equipment with an ammeter shall be calibrated at least once a year, or whenever the equipment has been subjected to major electric repair, periodic overhaul, or damage. If equipment has not been in use for a year or more, calibration shall be done prior to first use.

(b) *Procedure.* The accuracy of the unit's meter shall be verified annually by equipment traceable to a national standard. Comparative readings shall be taken for at least three different current output levels encompassing the usable range.

(c) *Tolerance.* The unit's meter reading shall not deviate by more than $\pm 10\%$ of full scale, relative to the actual current value as shown by the test meter.

T-762 Lifting Power of Yokes

(a) Prior to use, the magnetizing power of electromagnetic yokes shall have been checked within the past year. The magnetizing power of permanent magnetic yokes shall be checked daily prior to use. The magnetizing power of all yokes shall be checked whenever the yoke has been damaged or repaired.

(b) Each alternating current electromagnetic yoke shall have a lifting power of at least 10 lb (4.5 kg) at the maximum pole spacing that will be used.

(c) Each direct current or permanent magnetic yoke shall have a lifting power of at least 40 lb (18.1 kg) at the maximum pole spacing that will be used.

(d) Each weight shall be weighed with a scale from a reputable manufacturer and stenciled with the applicable nominal weight prior to first use. A weight need only be verified again if damaged in a manner that could have caused potential loss of material.

T-763 Gaussmeters

Hall-Effect probe gaussmeters used to verify magnetizing field strength in accordance with T-753 shall be calibrated at least once a year or whenever the equipment has been subjected to a major repair, periodic overhaul, or damage. If equipment has not been in use for a year or more, calibration shall be done prior to first use.

T-770 EXAMINATION

T-771 Direction of Magnetization

At least two separate examinations shall be performed on each area. During the second examination, the lines of magnetic flux shall be approximately perpendicular to those used during the first examination. A different technique for magnetization may be used for the second examination.

T-772 Examination Coverage

All examinations shall be conducted with sufficient field overlap to ensure 100% coverage at the required sensitivity (T-753).

T-773 Prod Technique

T-773.1 Magnetizing Procedure. For the prod technique, magnetization is accomplished by portable prod type electrical contacts pressed against the surface in the area to be examined. To avoid arcing, a remote control switch, which may be built into the prod handles, shall be provided to permit the current to be turned on after the prods have been properly positioned.

T-773.2 Magnetizing Current. Direct or rectified magnetizing current shall be used. The current shall be 100 (minimum) amp/in. (3.9 amp/mm) to 125 (maximum) amp/in. (4.9 amp/mm) of prod spacing for sections $\frac{3}{4}$ in. (19 mm) thick or greater. For sections

less than $\frac{3}{4}$ in. (19 mm) thick, the current shall be 90 amp/in. (3.5 amp/mm) to 110 amp/in. (4.3 amp/mm) of prod spacing.

T-773.3 Prod Spacing. Prod spacing shall not exceed 8 in. (203 mm). Shorter spacing may be used to accommodate the geometric limitations of the area being examined or to increase the sensitivity, but prod spacings of less than 3 in. (76 mm) are usually not practical due to banding of the particles around the prods. The prod tips shall be kept clean and dressed. If the open circuit voltage of the magnetizing current source is greater than 25 V, lead, steel, or aluminum (rather than copper) tipped prods are recommended to avoid copper deposits on the part being examined.

T-774 Longitudinal Magnetization Technique

T-774.1 Magnetizing Procedure. For this technique, magnetization is accomplished by passing current through a multi-turn fixed coil (or cables) that is wrapped around the part or section of the part to be examined. This produces a *longitudinal* magnetic field parallel to the axis of the coil.

If a fixed, prewound coil is used, the part shall be placed near the side of the coil during inspection. This is of special importance when the coil opening is more than 10 times the cross-sectional area of the part.

T-774.2 Magnetic Field Strength. Direct or rectified current shall be used to magnetize parts examined by this technique. The required field strength shall be calculated based on the length L and the diameter D of the part in accordance with (a), (b), or as established in (c), below. Long parts shall be examined in sections not to exceed 18 in. (457 mm), and 18 in. (457 mm) shall be used for the part L in calculating the required field strength. For noncylindrical parts, D shall be the maximum cross-sectional diagonal.

(a) *Parts With L/D Ratios Equal to or Greater Than 4.* The magnetizing current shall be within $\pm 10\%$ of the ampere-turns' value determined as follows:

$$\text{Ampere-turns} = \frac{35,000}{(L/D) + 2}$$

For example, a part 10 in. long $\times$ 2 in. diameter has an L/D ratio of 5. Therefore,

$$\frac{35,000}{(5 + 2)} = 5000 \text{ ampere-turns}$$

(b) *Parts With L/D Ratios Less Than 4 but Not Less Than 2.* The magnetizing ampere-turns shall be

within $\pm 10\%$ of the ampere-turns' value determined as follows:

$$\text{Ampere-turns} = \frac{45,000}{L/D}$$

(c) If the area to be magnetized extends beyond 6 in. on either side of the coils, field adequacy shall be demonstrated using the magnetic field indicator per T-753.

(d) For large parts due to size and shape, the magnetizing current shall be 1200 ampere-turns to 4500 ampere-turns. The field adequacy shall be demonstrated using artificial flaw shims or a pie-shaped magnetic field indicator in accordance with T-753. A Hall-Effect probe gaussmeter shall not be used with encircling coil magnetization techniques.

T-774.3 Magnetizing Current. The current required to obtain the necessary magnetizing field strength shall be determined by dividing the ampere-turns obtained in steps (a) or (b) above by the number of turns in the coil as follows:

$$\text{Amperes (meter reading)} = \frac{\text{ampere-turns}}{\text{turns}}$$

For example, if a 5-turn coil is used and the ampere-turns required are 5000, use

$$\frac{5000}{5} = 1000 \text{ amperes } (\pm 10\%)$$

T-775 Circular Magnetization Technique

T-775.1 Direct Contact Technique

(a) *Magnetizing Procedure.* For this technique, magnetization is accomplished by passing current through the part to be examined. This produces a *circular* magnetic field that is approximately perpendicular to the direction of current flow in the part.

(b) *Magnetizing Current.* Direct or rectified (half-wave rectified or full-wave rectified) magnetizing current shall be used.

(1) The current shall be 300 amp/in. (12A/mm) to 800 amp/in. (31A/mm) of outer diameter.

(2) Parts with geometric shapes other than round with the greatest cross-sectional diagonal in a plane at right angles to the current flow shall determine the inches to be used in (b)(1) above.

(3) If the current levels required for (b)(1) cannot be obtained, the maximum current obtainable shall be

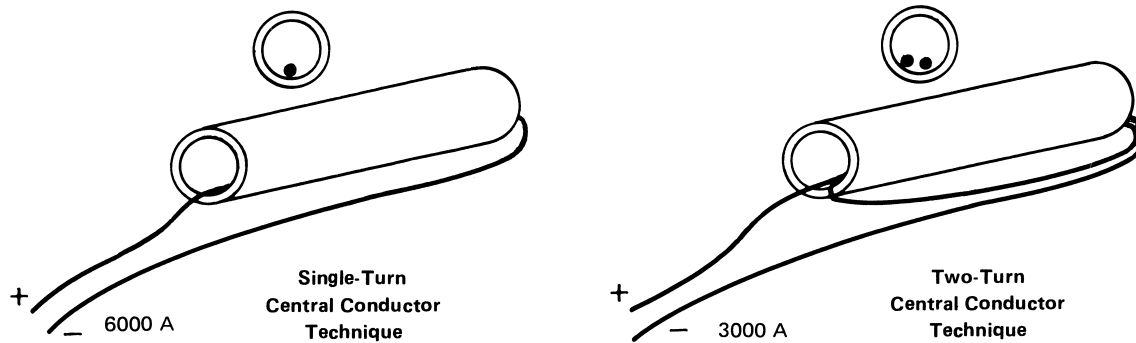


FIG. T-775.2 SINGLE-TURN AND TWO-TURN CENTRAL CONDUCTOR TECHNIQUE

used and the field adequacy shall be demonstrated in accordance with T-753.

T-775.2 Central Conductor Technique

(a) *Magnetizing Procedure.* For this technique, a central conductor is used to examine the internal surfaces of cylindrically or ring-shaped parts. The central conductor technique may also be used for examining the outside surfaces of these shapes. Where large diameter cylinders are to be examined, the conductor shall be positioned close to the internal surface of the cylinder. When the conductor is not centered, the circumference of the cylinder shall be examined in increments. Field strength measurements in accordance with T-753 shall be used to determine the extent of the arc that may be examined for each conductor position. Bars or cables, passed through the bore of a cylinder, may be used to induce circular magnetization.

(b) *Magnetizing Current.* The field strength required shall be equal to that determined in T-775.1(b) for a single-turn central conductor. The magnetic field will increase in proportion to the number of times the central conductor cable passes through a hollow part. For example, if 6000 amperes are required to examine a part using a single central conductor, then 3000 amperes are required when 2 turns of the through-cable are used, and 1200 amperes are required if 5 turns are used (see Fig. T-775.2). When the central conductor technique is used, magnetic field adequacy shall be verified using a magnetic particle field indicator in accordance with T-753.

T-776 Yoke Technique

T-776.1 Application. This method shall only be applied to detect discontinuities that are open to the surface of the part.

T-776.2 Magnetizing Procedure. For this technique alternating or direct current electromagnetic yokes, or permanent magnet yokes, shall be used.

NOTE: Except for materials $\frac{1}{4}$ in. (6 mm) or less in thickness, alternating current yokes are superior to direct or permanent magnet yokes of equal lifting power for the detection of surface discontinuities.

T-777 Multidirectional Magnetization Technique

T-777.1 Magnetizing Procedure. For this technique magnetization is accomplished by high amperage power packs operating as many as three circuits that are energized one at a time in rapid succession. The effect of these rapidly alternating magnetizing currents is to produce an overall magnetization of the part in multiple directions. Circular or longitudinal magnetic fields may be generated in any combination using the various techniques described in T-774 and T-775.

T-777.2 Magnetic Field Strength. Only three phase, full-wave rectified current shall be used to magnetize the part. The initial magnetizing current requirements for each circuit shall be established using the previously described guidelines (see T-774 and T-775). The adequacy of the magnetic field shall be demonstrated using artificial flaw shims or a pie-shaped magnetic particle field indicator in accordance with T-753. A Hall-Effect probe gaussmeter shall not be used to measure field adequacy for the multidirectional magnetization technique. An adequate field shall be obtained in at least two nearly perpendicular directions, and the field intensities shall be balanced so that a strong field in one direction does not overwhelm the field in the other direction. For areas where adequate field strengths cannot be demonstrated, additional magnetic particle

techniques shall be used to obtain the required two-directional coverage.

T-778 Interpretation

- 01 T-778.1 Nonfluorescent Particles.** With nonfluorescent particles, the examination is performed using visible light. A minimum light intensity of 100 fc (1000 Lx) is required to ensure adequate sensitivity during the examination and evaluation of indications. The light source, technique used, and light level verification is required to be demonstrated one time, documented, and maintained on file.

T-778.2 Fluorescent Particles. With fluorescent particles the examination is performed using an ultraviolet light, called *black light*. The examination shall be performed as follows:

- (a) It shall be performed in a darkened area.
- (b) The examiner shall be in the darkened area for at least 5 min prior to performing the examination to enable his eyes to adapt to dark viewing. If the examiner wears glasses or lenses, they shall not be photosensitive.
- (c) The black light shall be allowed to warm up for a minimum of 5 min prior to use or measurement of the intensity of the ultraviolet light emitted.
- (d) The black light intensity shall be measured with a black light meter. A minimum of 1000 $\mu\text{W}/\text{cm}^2$ on the surface of the part being examined shall be required. The black light intensity shall be measured at least

once every 8 hr, and whenever the work station is changed.

T-780 EVALUATION

- (a) All indications shall be evaluated in terms of the acceptance standards of the referencing Code Section.
- (b) Discontinuities on or near the surface are indicated by retention of the examination medium. However, localized surface irregularities due to machining marks or other surface conditions may produce false indications.
- (c) Broad areas of particle accumulation, which might mask indications from discontinuities, are prohibited, and such areas shall be cleaned and re-examined.

T-790 RECORDS

T-791 Multidirectional Magnetization Technique Sketch

A technique sketch shall be prepared for each different geometry examined, showing the part geometry, cable arrangement and connections, magnetizing current for each circuit, and the areas of examination where adequate field strengths are obtained. Parts with repetitive geometries, but different dimensions, may be examined using a single sketch provided that the magnetic field strength is adequate when demonstrated in accordance with T-777.2.

ARTICLE 7

MANDATORY APPENDICES

APPENDIX I — MAGNETIC PARTICLE EXAMINATION ON COATED FERRITIC MATERIALS USING THE AC YOKE TECHNIQUE

I-710 SCOPE

This Appendix provides the Magnetic Particle examination methodology and equipment requirements applicable for performing Magnetic Particle examination on coated ferritic materials.

I-720 GENERAL

I-721 Personnel Qualification

Personnel qualification requirements shall be in accordance with the referencing Code Section.

I-730 EQUIPMENT

I-730.1 The magnetizing equipment shall be in accordance with Article 7.

I-730.2 When the dry powder technique is used, a powder blower shall be utilized for powder application. Hand squeezed particle applicators shall not be used when the dry powder technique is utilized.

I-730.3 Magnetic particles shall contrast with the component background.

I-730.4 Nonconductive materials such as plastic shim stock may be used to simulate nonconductive coatings for procedure and personnel qualification.

I-750 PROCEDURE/TECHNIQUE

I-750.1 Procedure

Magnetic particle examination shall be performed in accordance with a written procedure. The procedure shall include the following:

(a) identification of surface configurations to be examined, including coating materials, maximum qualified coating thickness, and product forms (e.g., base material or welded surface)

(b) surface condition requirements and preparation methods

(c) manufacturer and model of AC yoke

(d) manufacturer and type of magnetic particles

(e) minimum and maximum yoke leg separation

(f) method of measuring coating thickness

(g) identification of the steps in performing the examination

(h) minimum lighting and AC yoke lifting power requirements (as measured in accordance with Procedure Qualification I-752)

(i) methods of identifying flaw indications and discriminating between flaw indications and nonrelevant indications (e.g., magnetic writing or particle held by surface irregularities)

(j) instructions for identification and confirmation of suspected flaw indications

(k) recording criteria

(l) personnel qualification requirements

(m) reference to the procedure qualification records

(n) method of verifying that the yoke lifting power and the illumination source used in the production examination are at least as great as specified.

I-751 Coating Thickness Measurement

The procedure demonstration and performance of examinations shall be preceded by measurement of the coating thickness in the areas to be examined. If the coating is nonconductive, an eddy current technique may be used to measure the coating thickness. If the coating is conductive, a magnetic coating thickness technique shall be used in accordance with ASTM D 1186. Coating measurement equipment shall be used in accordance with the equipment manufacturer's instructions. Coating thickness measurements shall be taken at the intersections of a 2 in. (51 mm) maximum

grid pattern over the area of examination and at least one-half the maximum yoke leg separation beyond the examination area. The thickness shall be the mean of three separate readings within $\frac{1}{4}$ in. (6 mm) of each intersection.

I-752 Procedure Demonstration

The procedure shall be demonstrated to the satisfaction of the Inspector in accordance with the requirements of the referencing Code Section.

I-753 Procedure Qualification

(a) A qualification specimen is required. The specimen shall be of similar geometry or weld profile and contain at least one surface crack no longer than the maximum flaw size allowed in the applicable acceptance criteria. The material used for the specimen shall be the same specification and heat treatment as the coated ferromagnetic material to be examined. As an alternative to the material requirement, other materials and heat treatments may be qualified provided:

(1) The measured yoke maximum lifting force on the material to be examined is equal to or greater than the maximum lifting force on the qualification specimen material. Both values shall be determined with the same or comparable equipment and shall be documented as required in paragraph (c).

(2) All the requirements of paragraphs (b) through (g) are met for the alternate material.

(b) Examine the uncoated specimen in the most unfavorable orientation expected during the performance of the production examination.

(c) Document the measured yoke maximum lifting power, illumination levels, and the results.

(d) Measure the maximum coating thickness on the item to be examined in accordance with the requirements of I-751.

(e) Coat the specimen with the same type of coating, conductive or nonconductive, to the maximum thickness measured on the production item to be examined. Alternately, nonconductive shim stock may be used to simulate nonconductive coatings.

(f) Examine the coated specimen in the most unfavorable orientation expected during the performance of the production examination. Document the measured yoke maximum lifting power, illumination level, and examination results.

(g) Compare the length of the indication resulting from the longest flaw no longer than the maximum flaw size allowed by the applicable acceptance criteria,

before and after coating. The coating thickness is qualified when the length of the indication on the coated surface is at least 50% of the length of the corresponding indication prior to coating.

(h) Requalification of the procedure is required for a decrease in either the AC yoke lifting power or the illumination level, or for an increase in the coating thickness.

I-770 EXAMINATION

(a) Surfaces to be examined, and all adjacent areas within at least 1 in. (25 mm), shall be free of all dirt, grease, lint, scale, welding flux and spatter, oil, and loose, blistered, flaking, or peeling coating.

(b) Examine the coated item in accordance with the qualified procedure.

I-780 EVALUATION

If an indication greater than 50% of the maximum allowable flaw size is detected, the coating in the area of the indication shall be removed and the examination repeated.

I-790 DOCUMENTATION/RECORDS

Procedure qualification documentation shall include the following:

(a) identification of the procedure

(b) identification of the personnel performing and witnessing the qualification

(c) description and drawings or sketches of the qualification specimen, including coating thickness measurements and flaw dimensions

(d) equipment and materials used

(e) illumination level and yoke lifting power

(f) qualification results, including maximum coating thickness and flaws detected.

APPENDIX II — GLOSSARY OF TERMS FOR MAGNETIC PARTICLE EXAMINATION

II-710 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definition of terms

which appear in Article 7, Magnetic Particle Examination.

II-720 GENERAL REQUIREMENTS

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 Section 10 provides the definitions of terms listed in II-730(a).

(c) For general terms, such as *Indication*, *Flaw*, *Discontinuity*, *Evaluation*, etc., refer to Article 1, Mandatory Appendix I.

(d) Paragraph II-730(b) provides a list of terms and definitions, which are in addition to SE-1316 and are Code specific.

II-730 REQUIREMENTS

(a) The following SE-1316 terms are used in conjunction with this Article: ampere turns, black light, central conductor, circular magnetization, demagnetization, dry powder, full-wave direct current, half-wave current, longitudinal magnetization, magnetic field, magnetic field strength, magnetic particle examination, magnetic particle field indicator, magnetic particles, multidirectional magnetization, permanent magnet, prods, sensitivity, suspension, yoke.

(b) The following Code terms are used in conjunction with this Article:

black light intensity — a quantitative expression of ultraviolet irradiance

magnetic flux — the concept that the magnetic field is flowing along the lines of force suggests that these lines are therefore “flux” lines, and they are called magnetic flux. The strength of the field is defined by the number of flux lines crossing a unit area taken at right angles to the direction of the lines.

rectified magnetic current — by means of a device called a rectifier, which permits current to flow in one direction only, alternating current can be converted to unidirectional current. This differs from direct current in that the current value varies from a steady level. This variation may be extreme, as in the case of the half-wave rectified single phase AC, or slight, as in the case of three-phase rectified AC.

half-wave rectified current AC — when a single-phase alternating current is rectified in the simplest manner, the reverse of the cycle is blocked out entirely. The result is a pulsating unidirectional current with intervals when no current at all is flowing. This is often referred to as “half-wave” or pulsating direct current.

full-wave rectified current — when the reverse half of the cycle is turned around to flow in the same direction as the forward half. The result is full-wave rectified current. Three-phase alternating current when full-wave rectified is unidirectional with very little pulsation; only a ripple of varying voltage distinguishes it from straight DC single-phase, full rectified current is usually not employed for magnetic particle examination.

ARTICLE 7 — APPENDIX III

MAGNETIC FLUX LEAKAGE (MFL) EXAMINATION

III-710 SCOPE

This Appendix describes the Magnetic Flux Leakage (MFL) examination method equipment requirements applicable for performing MFL examinations on coated and uncoated ferromagnetic materials from one surface. MFL is generally used as a post construction examination method to evaluate the condition of plate materials, such as storage tank floors and piping for corrosion or other forms of degradation. Other imperfections that may be detected are cracks, seams, dents, laps, and nonmetallic inclusions, etc.

III-711 References

When the Magnetic Flux Leakage method of Article 7, Appendix III is specified by a referencing Code Section, the MFL method shall be used together with Article 1, General Requirements.

III-720 GENERAL

III-721 Personnel Qualification Requirements

The user of this Appendix shall be responsible for documented training, qualification, and certification of personnel performing MFL examination. Personnel performing supplemental examinations, such as ultrasonic (UT) examinations, shall be qualified in accordance with the referencing Code Section.

III-722 Equipment Qualification Requirements

The equipment operation shall be demonstrated by successfully completing the unit verification and function tests outlined as follows:

(a) *Reference Plate.* All MFL examinations shall have a reference plate to ensure the equipment is performing in accordance with the manufacturer's specifications, prior to use. The reference plate shall consist of a plate that is made from a material of the same nominal thickness, product form, and composition as

the component to be examined. The plate shall have notches, drilled holes, or other discontinuities machined into the bottom side of the plate, as shown in Figure III-722. The depths and widths of artificial discontinuities should be similar to the sizes and physical characteristics of discontinuities to be detected. If coatings or temporary coverings will be present during the examination, the reference plate shall be coated or covered with the coatings or covers representative of the maximum thickness that will be encountered during the examination.

(b) *System Verification and Function Checks.* The manufacturer's verification procedure shall be conducted initially to ensure that the system is functioning as designed. The functional check shall be made by scanning the reference plate over the range of scanning speeds to be utilized during the examination. Equipment settings shall be documented.

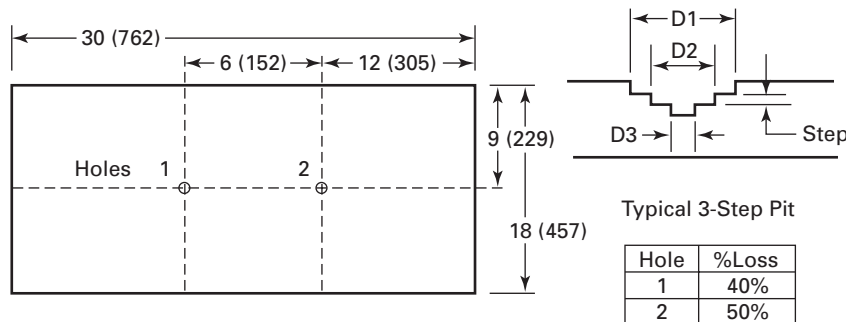
(c) *Performance Confirmation.* A functional check shall be conducted at the beginning and end of each examination, every eight hours, or when equipment has malfunctioned and been repaired. If it is determined that the equipment is not functioning properly, needed adjustments shall be made and all areas examined since the last performance check shall be re-inspected.

III-723 Written Procedure Requirements

III-723.1 Requirements. Magnetic Flux Leakage examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table III-723. The written procedure shall establish a single value, or range of values, for each requirement.

III-723.1.1 The procedure shall address, as a minimum, the identification of imperfections, reference materials used to set up equipment, location and mapping of imperfections, and the extent of coverage. The procedure shall address the field strength of the magnets, the functioning of the sensors and the operation of the signal-processing unit. Other examination methods that will be used to supplement the MFL examination shall be identified in the procedure.

Plate Thickness	Hole Number	Number of Steps	Step Size	Diameter D1	Diameter D2	Diameter D3	Diameter D4	Diameter D5
.25 (6)	1	3	.032 (0.8)	.47 (12)	.32 (8)	.12 (3)		
	2	4	.032 (0.8)	.62 (16)	.47 (12)	.32 (8)	.12 (3)	
.31 (8)	1	4	.032 (0.8)	.62 (16)	.47 (12)	.32 (8)	.16 (4)	
	2	5	.032 (0.8)	.78 (20)	.62 (16)	.47 (12)	.32 (8)	.16 (4)
.38 (10)	1	4	.039 (1)	.78 (20)	.59 (15)	.39 (10)	.2 (5)	
	2	5	.039 (1)	.96 (24.5)	.78 (20)	.59 (15)	.39 (10)	.2 (5)



GENERAL NOTE: Dimensions of references are in in. (mm).

FIG. III-722 MFL REFERENCE PLATE DIMENSIONS

III-723.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement in Table III-723, identified as an essential variable from the specified value, or range of values, shall require requalification of the written procedure. A change of a requirement identified as a nonessential variable from the specified value or range of values, does not require requalification of the written procedure. All changes of essential or nonessential variables from the value or range of values specified by the written procedure shall require revision of or an addendum to the written procedure.

III-730 EQUIPMENT

The equipment shall consist of magnets, sensor or sensor array, and related electronic circuitry. A reference indicator, such as a ruled scale or linear array of illuminated light emitting diodes, should be used to provide a means for identifying the approximate lateral position of indications. The equipment may be designed for manual scanning or may be motor driven. Software may be incorporated to assist in detection and characterization of discontinuities.

TABLE III-723
REQUIREMENTS OF AN MFL EXAMINATION
PROCEDURE

Requirement	Essential Variable	Non-Essential Variable
Equipment Manufacturer/Model	X	
Sensor Type; Manufacturer and Model	X	
Scanning Speed/Speed Range	X	
Scanning Technique (Remote Control/Manual)		X
Overlap	X	
Lift-off	X	
Material examined	X	
Material Thickness Range and Dimensions	X	
Reference Plate and Calibration Materials	X	
Scanning Equipment/Fixtures		X
Data Recording Equipment		X
Software	X	
Evaluation of Indications	X	
Surface Conditioning	X	
Coating/Sheet	X	

III-740 REQUIREMENTS

(a) The surface shall be cleaned of all loose scale and debris that could interfere with the examination and movement of the scanner. The surface should be sufficiently flat to minimize excessive changes in lift-off and vibration. Alternate techniques will be required to handle variables exceeding those specified in the procedure.

(b) Cleaning may be accomplished using high-pressure water blast or by sandblasting. If the material is coated and the coating is not removed, it shall be demonstrated that the MFL equipment can detect the specified imperfections through the maximum thickness of the coating.

(c) If a temporary sheet or coating is applied between the scanner and plate to provide a smooth surface, for example, on a heavily pitted surface, it must be demonstrated that the equipment can find the specified imperfections through the maximum thickness of the temporary sheet or coating.

III-760 CALIBRATION

The MFL equipment shall be recalibrated annually and whenever the equipment is subjected to major damage following required repairs. If equipment has not been in use for a year or more, calibration shall be done prior to first use.

III-770 EXAMINATION

(a) Areas to be examined shall be scanned in accordance with the written procedure. Each pass of the sensing unit shall be overlapped in accordance with the written procedure.

(b) The unit shall be scanned manually or by a motor driven system. Other examination methods may be used to provide coverage in areas not accessible to MFL examinations, in accordance with the written

procedure. Typical examples of inaccessible areas in storage tanks are lap welds and corner welds adjacent to the shell or other obstructions, such as roof columns and sumps.

(c) Imperfections detected with MFL during this procedure shall be confirmed by supplemental examination. Supplemental examinations shall be performed in accordance with written procedures.

(d) Where detection of linear imperfections is required, an additional scan shall be performed in a direction approximately perpendicular to the initial scanning direction.

III-780 EVALUATION

All indications shall be evaluated in accordance with the referencing Code Section.

III-790 DOCUMENTATION

A report of the examination shall contain the following information:

(a) plate material specification, nominal wall thickness, pipe diameter, as applicable;

(b) description, such as drawing/sketches, documenting areas examined, and/or areas inaccessible;

(c) identification of the procedure used for the examination;

(d) system detection sensitivity (minimum size of imperfections detectable);

(e) location, depth, and type of all imperfections that meet or exceed the reporting criteria;

(f) examination personnel identity, and, when required by referencing Code Section, qualification level;

(g) model and serial number of equipment utilized for the examination, including supplemental equipment;

(h) date and time of examination;

(i) date and time of performance verification checks;

(j) supplemental methods utilized and referenced to associated reports.

ARTICLE 7

NONMANDATORY APPENDIX

APPENDIX A — MEASUREMENT OF TANGENTIAL FIELD STRENGTH WITH GAUSSMETERS

A-710 SCOPE

This Nonmandatory Appendix is used for the purpose of establishing procedures and equipment specifications for measuring the tangential applied magnetic field strength.

A-720 GENERAL REQUIREMENTS

Personnel qualification requirements shall be in accordance with Article 1.

Gaussmeters and related equipment shall be calibrated in accordance with T-763 of Article 7.

Definitions: standard terminology for magnetic particle examinations is presented in SE-1316.

A-730 EQUIPMENT

Gaussmeter having the capability of being set to read peak values of field intensity. The frequency response of the gaussmeter shall be at least 0 Hz to 300 Hz.

The Hall-Effect tangential field probe should be no larger than 0.2 in. (5 mm) by 0.2 in. (5 mm) and should have a maximum center location 0.2 in. (5 mm) from the part surface. Probe leads shall be shielded or twisted to prevent reading errors due to voltage induced during the large field changes encountered during magnetic particle examinations.

A-750 PROCEDURE

Care must be exercised when measuring the tangential applied field strengths specified in T-753.1.3. The plane of the probe must be perpendicular to the surface of the part at the location of measurement to within 5 deg. This may be difficult to accomplish by hand orientation. A jig or fixture may be used to ensure this orientation is achieved and maintained.

The direction and magnitude of the tangential field on the part surface can be determined by placing the Hall-Effect tangential field probe on the part surface in the area of interest. The direction of the field can be determined during the application of the magnetizing field by rotating the tangential field probe while in contact with the part until the highest field reading is obtained on the Gaussmeter. The orientation of the probe, when the highest field is obtained, will indicate the field direction at that point. Gaussmeters cannot be used to determine the adequacy of magnetizing fields for multidirectional and coil magnetization techniques.

Once adequate field strength has been demonstrated with artificial flaw shims, Gaussmeter readings may be used at the location of shim attachment on identical parts or similar configurations to verify field intensity and direction.

A-790 DOCUMENTATION/RECORDS

Documentation should include the following:

- (a) equipment model and probe description;
- (b) sketch or drawing showing where measurements are made; and
- (c) field intensity and direction of measurement.

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ARTICLE 8

EDDY CURRENT EXAMINATION OF TUBULAR PRODUCTS

01 T-810 SCOPE

(a) This Article describes the method to be used when performing eddy current examination of seamless copper, copper alloy, and other nonferromagnetic tubular products. The method conforms substantially with the following Standard listed in Article 26 and reproduced in Subsection B:

SE-243 Electromagnetic (Eddy Current) Testing of Seamless Copper and Copper-Alloy Heat Exchanger and Condenser Tubes.

(b) The requirements of Article 1, General Requirements, also apply when eddy current examination, in accordance with Article 8, is required by a referencing Code Section.

(c) Definitions of terms for eddy current examination appear in Article 1, Appendix I, Subsection B, Article 30 and Mandatory Appendix IV of this Article.

T-820 GENERAL

01 T-821 Performance

Tubes may be examined at the finish size, after the final anneal or heat treatment, or at the finish size, prior to the final anneal or heat treatment, unless otherwise agreed upon between the supplier and the purchaser. The procedure shall be qualified by demonstrating detection of discontinuities of a size equal to or smaller than those in the reference specimen described in T-833. Indications equal to or greater than those considered reportable by the procedure shall be processed in accordance with T-880.

01 T-822 Personnel Requirements

The user of this Article shall be responsible for assigning qualified personnel to perform eddy current examinations to the requirements of this Article. Person-

TABLE T-823
REQUIREMENTS OF AN EDDY CURRENT
EXAMINATION PROCEDURE

Requirement (As Applicable)	Essential Variable	Non- Essential Variable
Frequency(s)	X	
Mode (Differential/Absolute)	X	
Minimum Fill Factor	X	
Probe Type	X	
Maximum Scanning Speed	X	
Scanning Technique (Automatic/Manual)		X
Material being examined	X	
Material Size/Dimensions	X	
Reference Standard	X	
Equipment Manufacturer/Model	X	
Scanning Equipment/Fixtures		X
Data Recording Equipment	X	
Cabling (Type and Length)	X	
Acquisition Software	X	
Analysis Software	X	

nel performing examinations shall be qualified as required by the referencing Code Section.

T-823 Procedure

T-823.1 Requirments. Eddy current or other electromagnetic examinations shall be performed in accordance with a written procedure, which shall, as a minimum contain the requirements listed in Table T-823. The written procedure shall establish a single value, or range of values, for each requirement.

T-823.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement in Table T-823 identified as an essential variable from the specified value, or range of values, shall require requalification of the written procedure. Where a range is specified for an essential variable, the bounding

values of the range shall be qualified by demonstration. A change of a requirement identified as a nonessential variable from the specified value, or range of values, does not require requalification of the written procedure. All changes of essential or nonessential variables from the value, or range of values, specified by the written procedure shall require revision of, or an addendum to, the written procedure.

01 T-830 EQUIPMENT

Equipment shall consist of electronic apparatus capable of energizing the test coil or probes with alternating currents of suitable frequencies and shall be capable of sensing the changes in the electromagnetic properties of the material. Output produced by this equipment may be processed so as to actuate signaling devices and/or to record examination data.

01 T-831 Test Coils and Probes

Test coils or probes shall be capable of inducing alternating currents into the material and sensing changes in the electromagnetic characteristics of the material. Test coils should be selected to provide the highest practical fill factor.

01 T-832 Scanners

Equipment used should be designed to maintain the material concentric within the coil, or to keep the probe centered within the tube and to minimize vibration during scanning. Maximum scanning speeds shall be based on the equipment's data acquisition frequency response or digitizing rate, as applicable.

01 T-833 Reference Specimen

The reference specimen material shall be processed in the same manner as the product being examined. It shall be the same nominal size and material type (chemical composition and product form) as the tube being examined. Ideally, the specimen should be a part of the material being examined. Unless specified in the referencing Code Section, the reference discontinuities shall be transverse notches or drilled holes as described in Standard Practice SE-243, Section 7, Calibration Standards.

T-840 REQUIREMENTS

T-841 Procedure Requirements

A written procedure, when required according to T-150, shall include at least the following:

- (a) frequency
- (b) type of coil or probe (e.g., differential coil)
- (c) type of material and sizes to which applicable
- (d) reference specimen notch or hole size
- (e) additional information as necessary to permit retesting

T-850 TECHNIQUE

Specific techniques may include special probe or coil designs, electronics, calibration standards, analytical algorithms and/or display software. Techniques, such as channel mixes, may be used as necessary to suppress signals produced at the ends of tubes. Such techniques shall be in accordance with requirements of the referencing Code Section.

T-860 CALIBRATION

T-861 Performance Verification

Performance of the examination equipment shall be verified by the use of the reference specimen as follows:

- (a) As specified in the written procedure:
 - (1) at the beginning of each production run of a given diameter and thickness of a given material;
 - (2) at the end of the production run;
 - (3) at any time that malfunctioning is suspected.
- (b) If, during calibration or verification, it is determined that the examination equipment is not functioning properly, all of the product tested since the last calibration or verification shall be re-examined.
- (c) When requalification of the written procedure as required in T-823.2.

T-862 Calibration of Equipment

(a) *Frequency of Calibration.* Eddy current instrumentation shall be calibrated at least once a year, or whenever the equipment has been subjected to a major electronic repair, periodic overhaul, or damage. If equipment has not been in use for a year or more, calibration shall be done prior to use.

(b) *Documentation.* A tag or other form of documentation shall be attached to the eddy current equipment with dates of the calibration and calibration due date.

01 T-870 EXAMINATION

Tubes are examined by passing through an encircling coil, or past a probe coil with the apparatus set up in accordance with the written procedure. Signals produced by the examination are processed and evaluated. Data may be recorded for post-examination analysis or stored for archival purposes in accordance with the procedure. Outputs resulting from the evaluation may be used to mark and/or separate tubes.

01 T-880 EVALUATION

Evaluation of examination results for acceptance shall be as specified in the written procedure and in accordance with the referencing Code Section.

01 T-890 DOCUMENTATION**01 T-891 Examination Reports**

A report of the examination shall contain the following information:

(a) tube material specification, diameter, and wall thickness condition

(b) coil or probe manufacturer, size and type

(c) mode of operation (absolute, differential, etc.)

(d) examination frequency or frequencies

(e) manufacturer, model, and serial number of eddy current equipment

(f) scanning speed

(g) examination procedure number and revision

(h) calibration standard and serial number

(i) identity of examination personnel, and, when required by the referencing Code Section, qualification level

(j) date of inspection

(k) list of acceptable material

(l) date and time of qualification

(m) results of requalification (as applicable)

T-892 Documentation of Performance Demonstration**01**

When required by the referencing Code Section, performance demonstrations shall be documented.

ARTICLE 8 — APPENDIX I

EDDY CURRENT EXAMINATION METHOD FOR INSTALLED NONFERROMAGNETIC HEAT EXCHANGER TUBING

I-800 INTRODUCTION

I-810 SCOPE

This Appendix defines the eddy current (ET) examination method and equipment requirements applicable to installed nonferromagnetic heat exchanger tubing. When specified by the referencing Code Section, the eddy current techniques described in this Appendix shall be used. The methods and techniques described in this Appendix are intended to detect and quantify degradation in the tubing.

I-820 GENERAL REQUIREMENTS

(a) The basis frequency ET examination is required and shall be done in accordance with I-862.

(b) The requirements for test equipment and examination procedures shall be in accordance with I-830.

(c) Calibrations shall be done in accordance with I-860.

(d) Examination shall be done in accordance with I-870.

I-830 EQUIPMENT

Eddy current nondestructive testing equipment capable of operation in the differential mode or the absolute mode, or both, shall be used for this examination. A device for recording data, real time, in a format suitable for evaluation and for archival storage, shall be provided when required by the referencing Code Section.

I-831 Frequency of Calibration

Electronic instrumentation of the eddy current system shall be calibrated at least once a year or whenever

the equipment has been overhauled or repaired as a result of malfunction or damage.

I-850 TECHNIQUE

Single frequency or multiple frequency techniques are permitted for this examination. Upon selection of the test frequency(s) and after completion of calibration, the probe shall be inserted into the tube where it is extended or positioned to the region of interest. Resulting eddy current signals at each of the individual frequencies shall be recorded for review, analysis, and final disposition.

I-860 CALIBRATION

I-861 Calibration Tube Standards

The calibration tube standard shall be manufactured from a length of tubing of the same nominal size and material type (chemical composition and product form) as that to be examined in the vessel. The intent of this reference standard is to establish and verify system response. The standard shall contain calibration discontinuities as follows.

(a) A single hole drilled 100% through the wall 0.052 in. (1.32 mm) diameter for $\frac{3}{4}$ in. (19 mm) O.D. tubing and smaller and 0.067 in. (1.70 mm) diameter for larger tubing.

(b) Four flat bottom holes, $\frac{3}{16}$ in. (4.8 mm) diameter, spaced 90 deg. apart in a single plane around the tube circumference, 20% through the tube wall from the O.D.

(c) A $\frac{1}{16}$ in. (1.6 mm) wide, 360 deg. circumferential groove, 10% through from the inner tube surface (optional).

(d) All calibration discontinuities shall be spaced so that they can be identified from each other and from the end of the tube.

(e) Each standard shall be identified by a serial number.

(f) The depth of the calibration discontinuities, at their center, shall be accurate to within $\pm 20\%$ of the specified depth or ± 0.003 in. (± 0.08 mm), whichever is smaller. All other dimensions shall be accurate to 0.010 in. (0.25 mm).

(g) The dimensions of the calibration discontinuities and the applicable ET system response shall become part of the permanent record of the standard.

I-862 Basis Frequency¹ Calibration Procedure

The examination system shall be calibrated utilizing the standard described in I-861.

(a) Basis Frequency Calibration Using Differential Bobbin Coil Technique

(1) Adjust the ET instrument for a basis frequency chosen so that the phase angle of a signal from the four 20% flat bottom holes is between 50 deg. and 120 deg. rotated clockwise from the signal of the through-the-wall hole (Fig. I-862-1).

(2) The trace display for the four 20% flat bottom holes shall be generated, when pulling the probe, in the directions illustrated in Fig. I-862-1: down and to the left first, followed by an upward motion to the right, followed by a downward motion returning to the point of origin.

(3) The sensitivity shall be adjusted to produce a minimum peak-to-peak signal from the four 20% flat bottom holes of 30% of the full scale horizontal presentation with the oscilloscope sensitivity set at 1 V per division.

(4) Adjust the phase or rotation control so that the signal response due to probe motion, or the 10% deep circumferential inside diameter groove, or both, is positioned along the horizontal axis of the display ± 5 deg. The responses from the calibration holes shall be maintained as described in (a)(1), (2), and (3) above.

(b) Basis Frequency Calibration Using Absolute Bobbin Coil Technique

(1) Adjust the ET instrument for a basis frequency so that the phase angle between a line drawn from the

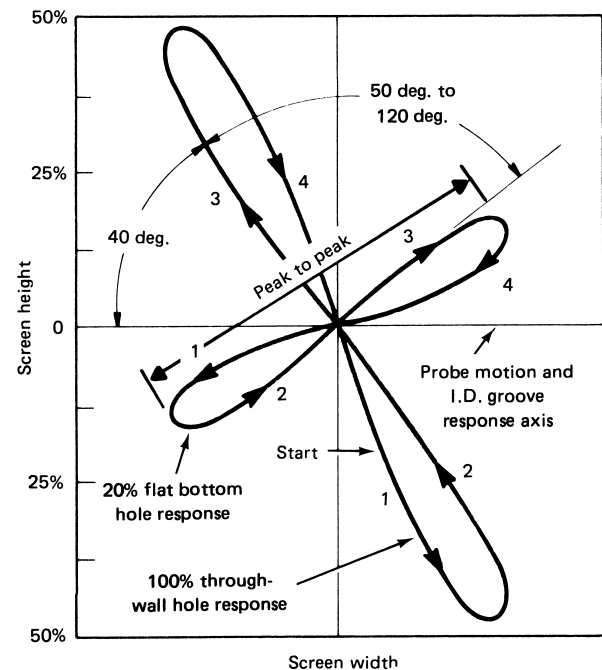


FIG. I-862-1 TYPICAL SIGNAL RESPONSE FROM A PROPERLY CALIBRATED DIFFERENTIAL BOBBIN COIL PROBE SYSTEM

origin to the tip of the response from the through-the-wall hole and the horizontal axis is approximately 40 deg. The phase angle formed by a line drawn from the origin to the tip of the response of the four 20% flat bottom holes and the through-the-wall response line is between 50 deg. and 120 deg. (see Fig. I-862-2).

(2) The sensitivity shall be adjusted to produce a minimum origin-to-peak signal from the four 20% flat bottom holes of 30% of the full scale horizontal presentation with the oscilloscope sensitivity set at 1 V per division.

(3) Adjust the phase or rotation control so that the signal response due to probe rotation, or the 10% deep circumferential inside diameter groove, or both, is positioned along the horizontal axis of the display ± 5 deg. The response of the calibration reference shall be maintained as described in (b)(1) and (2) above.

(4) The response may be rotated to the upper quadrants of the display at the option and convenience of the operator.

(5) Repeat withdrawing the probe through the calibration tube standard at the probe speed selected for the examination. Record the responses of the applicable calibration discontinuities. Ascertain that they are clearly

¹The basis frequency is that test frequency selected for the examination which provides responses from the 20% flat bottom holes and the 100% through-the-wall hole references in the calibration tube standard that have a phase angle difference between 50 deg. and 120 deg.

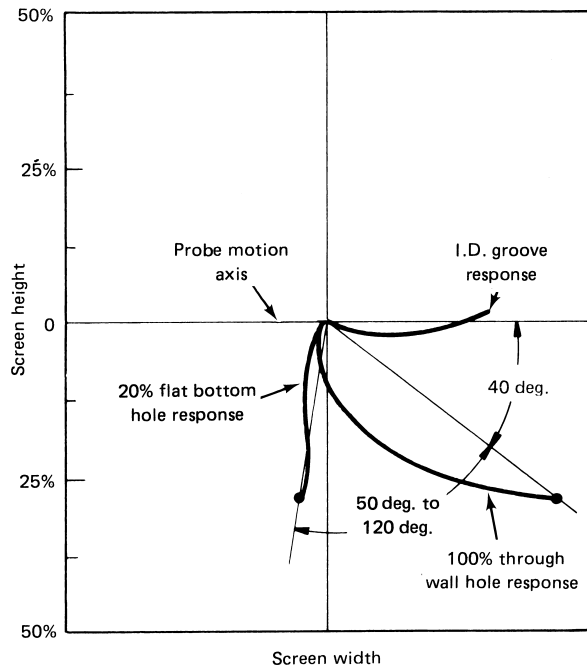


FIG. I-862-2 TYPICAL SIGNAL RESPONSE FROM A PROPERLY CALIBRATED ABSOLUTE BOBBIN COIL PROBE SYSTEM

indicated by the instrument and are distinguishable from each other as well as from probe motion signals.

I-863 Auxiliary Frequency(s) Calibration Procedure

(a) Auxiliary frequency(s) may be used to examine the tube wall. Reference standards other than that specified in I-861 may be used to establish examination specific sensitivity settings and an impedance plane phase reference.

(b) Auxiliary frequency(s) may be combined (mixed) with the basis frequency or with each other for extraneous variable suppression. When auxiliary frequency(s) are combined with the basis frequency for extraneous variable suppression, the basis frequency shall meet the requirements of I-862.

(c) Reference standards simulating the extraneous variables shall be used to establish mixing parameters. Auxiliary frequency response to the extraneous variable reference standard, or basis frequency response to the extraneous variable reference standard, or both, shall be a part of the calibration record.

(d) Repeat withdrawing the probe through the calibration standard at the probe speed selected for examina-

tion. Record the auxiliary frequency response of the applicable reference discontinuities.

(e) The basis frequency and auxiliary frequencies shall be recorded.

I-864 Calibration Confirmation

(a) Calibration shall include the complete ET examination system. Any change of probe, extension cables, ET instrument, recording instruments, or any other parts of the ET examination system hardware shall require recalibration.

(b) The system calibration hardware shall be confirmed as required by the referencing Code Section.

(c) Should the system be found to be out of calibration (as defined in I-862) the equipment shall be recalibrated. The recalibration shall be noted on the recording. The data analyst shall determine which tubes, if any, shall be re-examined.

I-865 Correlation of Signals to Estimate Depth of Discontinuities

The depth of discontinuities is primarily shown by the phase angle of the ET signal they produce. A relationship of reference comparator depths versus signal phase angle shall be developed for the examination being performed (see Fig. I-865-1). The following reference comparators may be used.

(a) The reference comparators shall be manufactured from a length of tubing of the same nominal size (diameter and wall thickness) and material (chemical composition and product form) as the tubes being examined.

(b) The reference comparators may be flat bottom holes drilled to varying depths.

(c) The drilled holes in the calibration standard (see I-861) may be used to establish this relationship where additional depths are required.

(d) The tolerance for the dimensions of the flat bottom holes shall be the same as those specified for the calibration tube standards [see I-861(g)].

(e) Except for the holes specified in (f)(1) below, all references shall be far enough apart to avoid interference between signals.

(f) When drilled holes are used, the dimensions shall be as follows:

(1) four flat bottom drill holes, $\frac{3}{16}$ in. (4.8 mm) diameter, 20% through the wall [same as the calibration tube standard (b) in I-861(b)];

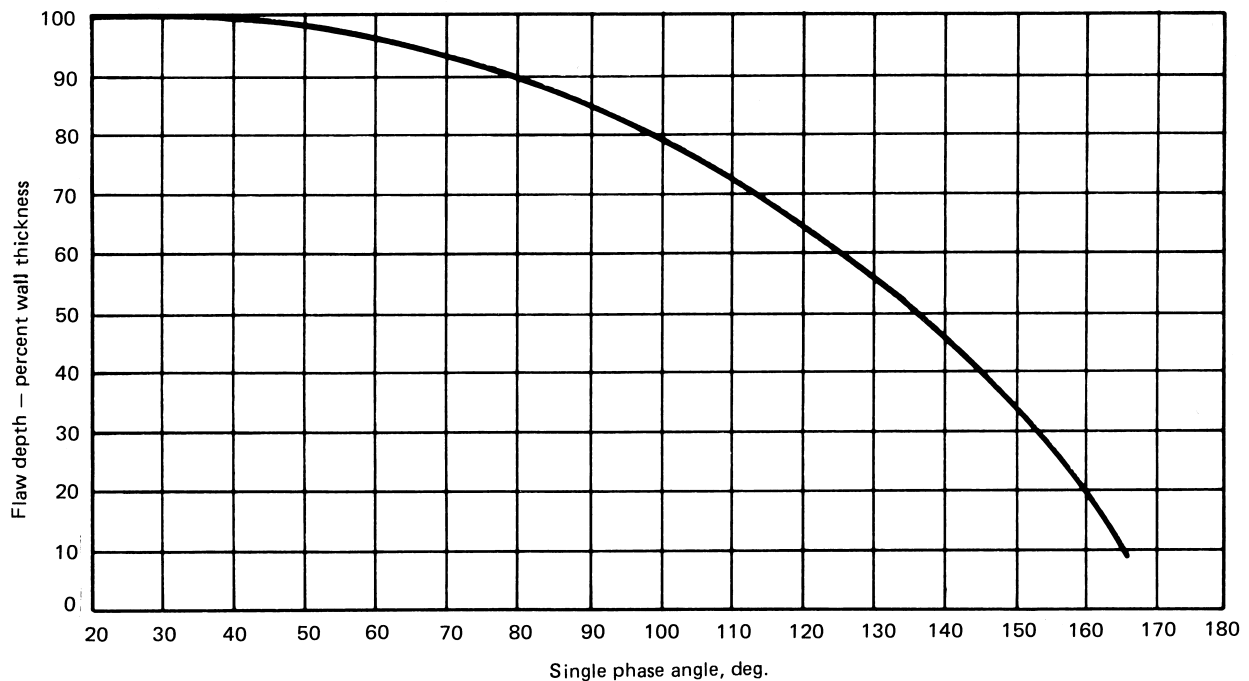


FIG. I-865-1 PHASE ANGLE vs FLAW DEPTH INCONEL TUBE, 400 kHz (TYPICAL 0.050 in. WALL TUBE)

(2) one flat bottom drill hole, $\frac{3}{16}$ in. (4.8 mm) in diameter $\times$ 40% through the wall from the outside surface;

(3) one flat bottom drill hole, $\frac{7}{64}$ in. (2.8 mm) in diameter $\times$ 60% through the wall from the outside surface;

(4) one flat bottom drill hole, $\frac{5}{64}$ in. (2.0 mm) in diameter $\times$ 80% through the wall from the outside surface;

(5) one through-the-wall drill hole [same as the calibration tube standard in I-861(a)].

(g) Other reference comparators may be used, provided that they can be demonstrated to be comparable to the intended discontinuity to be evaluated.

(h) Signal amplitude may be used to estimate depth for defects, which exhibit a known regularity in their growth history. Standards representative of the defect shall be used to generate an amplitude versus depth calibration curve.

I-870 EXAMINATION

I-871 General

Data shall be recorded as the probe traverses the tube.

I-872 Probe Speed

The nominal probe speed during examination shall not exceed 14 in./sec (356 mm/s). Higher probe speeds may be used if system frequency response and sensitivity to the applicable calibration standards described in I-861 can be demonstrated.

I-880 EVALUATION

I-881 General

The evaluation of examination data shall be made in accordance with the referencing Code Section.

I-890 DOCUMENTATION

I-891 Procedure Requirements

When required by the referencing Code Section, Eddy Current (ET) examinations shall be performed in accordance with a written procedure. Each procedure shall include at least the following information:

- (a) tube material, diameter, and wall thickness;
- (b) size and type of probes;

- (c) mode of operation (differential or absolute or both);
- (d) examination frequency or frequencies;
- (e) manufacturer and model of ET equipment;
- (f) scanning speed during examination;
- (g) examination technique, i.e., hand probe, mechanized probe drive, remote control fixture, etc.;
- (h) calibration procedure and calibration tube standards;
- (i) data recording equipment and procedures;
- (j) procedure for interpretation of results;
- (k) additional information as necessary to describe the examination.

ARTICLE 8 — APPENDIX II

EDDY CURRENT EXAMINATION OF NONFERROMAGNETIC HEAT EXCHANGER TUBING

II-810 SCOPE

This Appendix provides the requirements for bobbin coil, multifrequency, multiparameter, Eddy Current examination for nonferromagnetic heat exchanger tubing.

II-820 GENERAL

This Appendix also provides the methodology for examining nonferromagnetic, heat exchanger tubing using the eddy current method and bobbin coil technique. By scanning the tubing from the boreside, information will be obtained from which the condition of the tubing will be determined. Scanning is generally performed with a bobbin coil attached to a flexible shaft driven by a motorized device. Results are obtained by evaluating data recorded during scanning.

II-820.1 General Requirements

II-820.1.1 Procedure Requirements. Examinations shall be conducted in accordance with a written procedure. Each procedure shall include the following information:

- (a) tube material, diameter and wall thickness;
- (b) size and type of probes, including manufacturer's name, description or part number, and length of probe and probe extension cables;
- (c) examination frequencies;
- (d) manufacturer and model of eddy current equipment;
- (e) scanning direction and speed during examination (insertion, retraction, or both — from inlet or outlet end);
- (f) inspection technique, e.g., hand probe, mechanized probe driven, remote control fixture;
- (g) description of calibration procedure and calibration standards;
- (h) description of data recording equipment and procedures;
- (i) procedure for analysis of examination results and applicable criteria for reportable indications;

- (j) procedure for reporting examination results, e.g., 3 digit codes or reference points;
- (k) personnel requirements;
- (l) fixture location verification.

II-820.1.2 Personnel Requirements. Nondestructive examination personnel shall be qualified in accordance with the requirements of the referencing Code Section.

II-830 EQUIPMENT

II-830.1 Data Acquisition System

II-830.1.1 General System Requirements

(a) The eddy current instrument shall have the capability of generating multiple frequencies simultaneously or multiplexed and be capable of multiparameter signal combination. In the selection of frequencies, consideration shall be given to optimizing flaw detection and characterization.

(b) The outputs from the eddy current instrument shall provide phase and amplitude information.

(c) The eddy current equipment shall be capable of detecting and recording dimensional changes, metallurgical changes and foreign material deposits, and responses from flaws originating on either tube wall surface.

II-830.2 Analog Data Acquisition System

II-830.2.1 Eddy Current Instrument

(a) The frequency response of the outputs from the eddy current instrument shall be constant within $\pm 2\%$ of full scale from dc to $F_{\max}$, where $F_{\max}$ (Hz) is equal to 10 (Hz-sec/in.) [0.4 (Hz-sec/mm)] times maximum probe travel speed (in./sec).

(b) Eddy current signals shall be displayed as two-dimensional patterns by use of an X-Y storage oscilloscope or equivalent.

(c) The frequency response of the instrument output shall be constant within $\pm 2\%$ of the input value from

dc to $F_{\max}$, where $F_{\max}$ (Hz) is equal to 10 (Hz-sec/in.) [0.4 (Hz-sec/mm)] times maximum probe travel speed.

II-830.2.2 Magnetic Tape Recorder

(a) The magnetic tape recorder shall be capable of recording and playing back eddy current signal data from all test frequencies and shall have voice logging capability.

(b) The frequency response of the magnetic tape recorder outputs shall be constant within $\pm 10\%$ of the input value from dc to $F_{\max}$, where $F_{\max}$ (Hz) is equal to 10 (Hz-sec/in.) times maximum probe travel speed.

(c) Signal reproducibility from input to output shall be within $\pm 5\%$.

II-830.2.3 Strip Chart Recorder

(a) Strip chart recorders used during the examination shall have at least 2 channels.

(b) The frequency response of the strip chart recorder shall be constant within $\pm 20\%$ of full scale from dc to $F_{\max}$, where $F_{\max}$ (Hz) is equal to 10 (Hz-sec/in.) [0.4 (Hz-sec/mm)] times maximum probe travel speed.

II-830.3 Digital Data Acquisition System

II-830.3.1 Eddy Current Instrument

(a) At the scanning speed to be used, the sampling rate of the instrument shall result in a minimum digitizing rate of 30 samples per in. (25 mm) of examined tubing, using $dr = sr/ss$, where dr is the digitizing rate in samples per in., sr is the sampling rate in samples per sec or Hz, and ss is the scanning speed in in. per sec.

(b) The digital eddy current instrument shall have a minimum resolution of 12 bits per data point.

(c) The frequency response of the outputs of analog portions of the eddy current instrument shall be constant within $\pm 2\%$ of the input value from dc to $F_{\max}$, where $F_{\max}$ (Hz) is equal to 10 (Hz-s/in.) [0.4 (Hz-sec/mm)] times maximum probe travel speed.

(d) The display shall be selectable so that the examination frequency or mixed frequencies can be presented as a Lissajous pattern.

(e) The Lissajous display shall have a minimum resolution of 7 bits full scale.

(f) The strip chart display shall be capable of displaying at least 2 traces.

(g) The strip chart display shall be selectable so either the X or Y component can be displayed.

(h) The strip chart display shall have a minimum resolution of 6 bits full scale.

II-830.3.2 Recording System

(a) The recording system shall be capable of recording and playing back all acquired eddy current signal data from all test frequencies.

(b) The recording system shall be capable of recording and playing back text information.

(c) The recording system shall have a minimum resolution of 12 bits per data point.

II-830.4 Bobbin Coils

II-830.4.1 General Requirements

(a) Bobbin coils shall be able to detect calibration standard discontinuities.

(b) Bobbin coils shall have sufficient bandwidth for operating frequencies selected for flaw detection and sizing.

II-830.5 Data Analysis System

II-830.5.1 General System Requirements

(a) The data analysis system shall be capable of displaying eddy current signal data from all test frequencies.

(b) The system shall have multiparameter mixing capability.

(c) The system shall be capable of maintaining the identification of each tube recorded.

(d) The system shall be capable of measuring phase angles in increments of one degree or less.

(e) The system shall be capable of measuring amplitudes to the nearest 0.1 volt.

II-830.6 Analog Data Analysis System

II-830.6.1 Display. Eddy current signals shall be displayed as Lissajous patterns by use of an X-Y storage display oscilloscope or equivalent. The frequency response of the display device shall be constant within $\pm 2\%$ of the input value from dc to $F_{\max}$, where $F_{\max}$ (Hz) is equal to 10 (Hz-sec/in.) [0.4 (Hz-sec/mm)] times maximum probe travel speed.

II-830.6.2 Recording System

(a) The magnetic tape recorder shall be capable of playing back the recorded data.

(b) The frequency response of the magnetic tape recorder outputs shall be constant within $\pm 10\%$ of the input value from dc to $F_{\max}$, where $F_{\max}$ (Hz) is equal to 10 (Hz-sec/in.) times maximum probe travel speed (in./sec).

(c) Signal reproducibility input to output shall be within $\pm 5\%$.

II-830.7 Digital Data Analysis System**II-830.7.1 Display**

(a) The analysis display shall be capable of presenting recorded eddy current signal data and text information.

(b) The analysis system shall have a minimum resolution of 12 bits per data point.

(c) The Lissajous pattern display shall have a minimum resolution of 7 bits full scale.

(d) The strip chart display shall be selectable so either the X or Y component of any examination frequency or mixed frequencies can be displayed.

(e) The strip chart display shall have a minimum resolution of 6 bits full scale.

II-830.7.2 Recording System

(a) The recording system shall be capable of playing back all recorded eddy current signal data and text information.

(b) The recording system shall have a minimum resolution of 12 bits per data point.

II-830.8 Hybrid Data Analysis System

(a) For a hybrid system using both digital elements and some analog elements, individual elements shall meet II-830.1 and either II-830.2 or II-830.3, as applicable.

(b) If analog to digital or digital to analog converters are used, the frequency response of the analog element outputs shall be constant within $\pm 5\%$ of the input value from dc to $F_{\max}$, where $F_{\max}$ (Hz) is equal to 10 (Hz-sec/in.) [0.4 (Hz-sec/mm)] times maximum probe travel speed.

II-840 REQUIREMENTS**II-840.1 General Requirements**

(a) The eddy current signal data from all test frequencies shall be recorded on the recording media as the probe traverses the tube.

(b) The sensitivity for the differential bobbin coil technique shall be sufficient to produce a response from the through-wall holes with a minimum vertical amplitude of 50% of the full Lissajous display height.

II-840.2 Probe Traverse Speed. The traverse speed shall not exceed that which provides adequate frequency response and sensitivity to the applicable calibration discontinuities.

II-840.3 Fixture Location Verification

(a) The ability of the fixture to locate specific tubes shall be verified visually and recorded upon installation of the fixture and before relocating or removing the fixture.

(b) When the performance of fixture location reveals that an error has occurred in the recording of probe verification location, the tubes examined since the previous location verification shall be re-examined.

II-840.4 Automated Data Screening System. When automated eddy current data screening systems are used, each system shall be qualified in accordance with a written procedure.

II-860 CALIBRATION**II-860.1 Equipment Calibration****II-860.1.1 Analog Equipment**

The following shall be verified by annual calibration.

(a) The oscillator output frequency to the drive coil shall be within $\pm 5\%$ of its indicated frequency.

(b) The vertical and horizontal linearity of the cathode ray tube (CRT) display shall be within $\pm 10\%$ of the deflection of the input voltage.

(c) The CRT vertical and horizontal trace alignment shall be within ± 2 deg. of parallel to the graticule lines.

(d) The ratio of the output voltage from the tape recorder shall be within $\pm 5\%$ of the input voltage for each channel of the tape recorder.

(e) The chart speed from the strip chart recorder shall be within $\pm 5\%$ of the indicated value.

(f) Amplification for all channels of the eddy current instrument shall be within 5% of the mean value, at all sensitivity settings, at any single frequency.

(g) The two output channels of the eddy current instrument shall be orthogonal within ± 3 deg. at the examination frequency.

II-860.1.2 Digital Equipment. Analog elements of digital equipment shall be calibrated in accordance with II-860.1.1. Digital elements need not be calibrated.

II-860.2 Calibration Standards

II-860.2.1 General Requirements. Calibration standards shall conform to the following:

(a) Calibration standards shall be manufactured from a tubing of the same material specification, same heat treatment, and same nominal size as that to be examined in the vessel.

(b) Tubing calibration standard materials heat treated differently from the tubing to be examined may be used when signal responses from the discontinuities described in II-860.2.2 are demonstrated to the Inspector to be equivalent in both the calibration standard and tubing of the same heat treatment as the tubing to be examined.

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(c) As an alternative to (a) and (b), calibration standards fabricated from UNS Alloy N06600 shall be manufactured from a length of tubing of the same material specification and same nominal size as that to be examined in the vessel.

(d) Discontinuities in calibration standards shall be spaced axially so they can be differentiated from each other and from the end of the tube. The as-built dimensions of the discontinuities and the applicable Eddy Current equipment response shall become part of the permanent record of the standard.

II-860.2.2 Calibration Standards for Differential and Absolute Bobbin Coil

(a) Calibration standards shall contain:

(1) One or both through-wall holes as follows:

(a) A 0.052 in. (1.32 mm) diameter hole for tubing with diameters of 0.750 in. (19 mm) and less, or a 0.067 in. (1.70 mm) hole for tubing with diameters greater than 0.750 in. (19 mm).

(b) Four holes spaced 90 deg. apart in a single plane around the tube circumference, 0.026 in. (0.66 mm) diameter for tubing with diameters of 0.750 in. (19 mm) and less and 0.033 in. (0.84 mm) diameter for tubing with diameters greater than 0.750 in. (19 mm).

(2) A flat-bottom hole 0.109 in. (2.8 mm) diameter, 60% through the tube wall from the outer surface.

(3) A flat-bottom hole 0.187 in. (4.8 mm) diameter, 40% through the tube wall from the outer surface.

(4) Four flat-bottom holes 0.187 in. (4.8 mm) diameter, spaced 90 deg. apart in a single plane around the tube circumference, 20% through the tube wall from the outer surface.

(b) The depth of the artificial discontinuities, at their center, shall be within $\pm 20\%$ of the specified depth or ± 0.003 in. (± 0.08 mm), whichever is less. All other dimensions shall be within ± 0.03 in. (± 0.8 mm).

(c) All artificial discontinuities shall be sufficiently separated to avoid interference between signals, except for the holes specified in (a)(1)(b) and (a)(4).

II-860.3 Analog System Calibration

II-860.3.1 Differential Bobbin Coil Technique

(a) The sensitivity shall be adjusted to produce a minimum peak-to-peak signal of 4 volts from the four 20% flat-bottom holes or 6 volts from the four through-wall drilled holes.

(b) The phase or rotation control shall be adjusted so the signal response due to the through-wall hole forms down and to the right first as the probe is withdrawn from the standard holding the signal response from the probe motion horizontal.

(c) Withdraw the probe through the calibration standard at the nominal examination speed. Record the responses of the applicable calibration discontinuities. The responses shall be clearly indicated by the instrument and shall be distinguishable from each other as well as from probe motion signals.

II-860.3.2 Absolute Bobbin Coil Technique

(a) The sensitivity shall be adjusted to produce a minimum origin-to-peak signal of 2 volts from the four 20% flat-bottom holes or 3 volts from the four through-wall drilled holes.

(b) Adjust the phase or rotation control so that the signal response due to the through-wall hole forms up and to the left as the probe is withdrawn from the standard holding the signal response from the probe motion horizontal.

(c) Withdraw the probe through the calibration standard at the nominal examination speed. Record the responses of the applicable calibration discontinuities. The responses shall be clearly indicated by the instrument and shall be distinguishable from each other as well as from probe motion signals.

II-860.4 Digital System Calibration. When the eddy current examination information is digitized and recorded for off-line analysis and interpretation, the system calibration phase and amplitude settings shall be performed off-line by the data analyst. Phase and amplitude settings shall be such that the personnel acquiring the data can clearly discern that the eddy current instrument is working properly.

II-860.4.1 System Calibration Verification

(a) Calibration shall include the complete eddy current examination system. Any change of probe, extension cables, eddy current instrument, recording instruments, or any other parts of the eddy current examination system hardware shall require recalibration.

(b) System calibration verification shall be performed and recorded at the beginning and end of each unit of data storage of the recording media.

(c) Should the system be found to be out of calibration (as defined in II-860.3), the equipment shall be recalibrated. The recalibration shall be noted on the recording and the data analyst shall determine which tubes, if any, shall be reexamined.

II-880 EVALUATION

II-880.1 Data Evaluation. Data shall be evaluated in accordance with the requirements of this Article.

II-880.2 Means of Determining Indication Depth.

For indication types that must be reported in terms of depth, a means of correlating the indication depth with the signal amplitude or phase shall be established. The means of correlating the signal amplitude or phase with the indication depth shall be based on the basic calibration standard or other representative standards that have been qualified. This shall be accomplished by using curves, tables, or software.

II-880.3 Frequencies Used for Data Evaluation.

All indications shall be evaluated. Indication types, which must be reported, shall be characterized using the frequencies or frequency mixes that were qualified.

II-890 DOCUMENTATION**II-890.1 Reporting**

II-890.1.1 Criteria. Indications reported in accordance with the requirements of this Article shall be described in terms of the following information, as a minimum:

- (a) location along the length of the tube and with respect to the support members
- (b) depth of the indication through the tube wall, when required by this Article
- (c) signal amplitude
- (d) frequency or frequency mix from which the indication was evaluated

II-890.1.2 Depth. The maximum evaluated depth of flaws shall be reported in terms of percentage of loss of tube wall. When the loss of tube wall is determined by the analyst to be less than 20%, the exact percentage of tube wall loss need not be recorded, i.e., the indication may be reported as being less than 20%.

II-890.1.3 Non-Quantifiable Indications. A non-quantifiable indication is a reportable indication that cannot be characterized. The indication shall be considered a flaw until otherwise resolved.

II-890.1.4 Support Members

II-890.1.4.1 Location of Support Members. The location of support members used as reference points for the eddy current examination shall be verified

by fabrication drawings or the use of a measurement technique.

II-890.2 Records

II-890.2.1 Record Identification. The recording media shall contain the following information within each unit of data storage:

- (a) owner
- (b) plant site
- (c) heat exchanger identification
- (d) data storage unit number
- (e) date of examination
- (f) serial number of the calibration standard
- (g) operator's identification and certification level
- (h) examination frequencies
- (i) lengths of probe and probe extension cables
- (j) size and type of probes
- (k) probe manufacturer's name and manufacturer's part number or probe description

II-890.2.2 Tube Identification

- (a) Each tube examined shall be identified on the applicable unit of data storage
- (b) The method of recording the tube identification shall correlate tube identification with corresponding recorded tube data.

II-890.2.3 Reporting

(a) The Owner or his agent shall prepare a report of the examinations performed. The report shall be prepared, filed, and maintained in accordance with the referencing Code Section. Procedures and equipment used shall be identified sufficiently to permit comparison of the examination results with new examination results run at a later date. This shall include initial calibration data for each eddy current examination system and subsequent rechecks.

(b) The report shall include a record indicating the tubes examined (this may be marked on a tubesheet sketch or drawing), any scanning limitations, the location and depth of each reported flaw, and the identification and certification level of the operators and data evaluators that conducted each examination or part thereof.

(c) Tubes that are to be repaired or removed from service, based on eddy current examination data, shall be identified.

ARTICLE 8 — APPENDIX III

EDDY CURRENT (ET) EXAMINATION ON COATED FERRITIC MATERIALS

01 III-810 SCOPE

(a) This Appendix provides the Eddy Current examination methodology and equipment requirements applicable for performing Eddy Current examination on coated ferritic materials.

(b) Article 1, General Requirements, also applies when Eddy Current examination of coated ferritic materials is required. Requirements for written procedures, as specified in Article 8, shall apply, as indicated.

(c) ASTM D 1186, Standard for Magnetic Thickness Measurement of Coatings, may be used as a procedure for measuring the thickness of conductive coatings.

III-820 GENERAL

III-821 Personnel Qualification

NDE personnel shall be qualified in accordance with the requirements of the referencing Code Section.

01 III-822 Procedure

The requirements of T-823 shall apply. The type of coating and maximum coating thickness shall be essential variables.

01 III-823 Procedure Demonstration

The procedure shall be demonstrated to the satisfaction of the Inspector in accordance with requirements of the referencing Code Section.

III-830 EQUIPMENT

The ET system shall include phase and amplitude display.

III-850 TECHNIQUE

III-851 Coating Thickness Measurement

The performance of examinations shall be preceded by measurement of the coating thickness in the areas to be examined. If the coating is nonconductive, an Eddy Current technique may be used to measure the coating thickness. If the coating is conductive, a magnetic coating thickness technique may be used in accordance with ASTM D 1186. Coating thickness measurement shall be used in accordance with the equipment manufacturer's instructions. Coating thickness measurements shall be taken at the intersections of a 2 in. (51 mm) maximum grid pattern over the area to be examined. The thickness shall be the mean of three separate readings within $\frac{1}{4}$ in. (6 mm) of each intersection.

III-852 Procedure Verification

(a) A qualification specimen is required. The material used for the specimen shall be the same specification and heat treatment as the coated ferromagnetic material to be examined. If a conductive primer was used on the material to be examined, the primer thickness on the procedure qualification specimen shall be the maximum allowed on the examination surfaces by the coating specification. Plastic shim stock may be used to simulate nonconductive coatings for procedure qualification. The thickness of the coating or of the alternative plastic shim stock on the procedure qualification specimen shall be equal to or greater than the maximum coating thickness measured on the examination surface.

(b) The qualification specimen shall include at least one crack. The length of the crack open to the surface shall not exceed the allowable length for surface flaws. The maximum crack depth in the base metal shall be between 0.020 and 0.040 in. (0.51 mm and 1.02 mm). In addition, if the area of interest includes weld metal, a 0.020 in. (0.51 mm) maximum depth crack is required in an as-welded and coated surface typical of the welds

to be examined. In lieu of a crack, a machined notch of 0.010 in. (0.25 mm) maximum width and 0.020 in. (0.51 mm) maximum depth may be used in the as-welded surface.

(c) Examine the qualification specimen first uncoated and then after coating to the maximum thickness to be qualified. Record the signal amplitudes from the qualification flaws.

(d) Using the maximum scanning speed, the maximum scan index, and the scan pattern specified by the procedure, the procedure shall be demonstrated to consistently detect the qualification flaws through the maximum coating thickness regardless of flaw orientation (e.g., perpendicular, parallel, or skewed to the scan direction). The signal amplitude from each qualification flaw in the coated qualification specimen shall be at least 50% of the signal amplitude measured on the corresponding qualification flaw prior to coating.

III-870 EXAMINATION

(a) Prior to the examination, all loose, blistered, flaking, or peeling coating shall be removed from the examination area.

(b) When conducting examinations, areas of suspected flaw indications shall be confirmed by application of another surface or volumetric examination method. It may be necessary to remove the surface coating prior to performing the other examination.

III-890 DOCUMENTATION 01

III-891 Examination Report 01

The report of examination shall contain the following information:

- (a) a procedure identification and revision
- (b) examination personnel identity, and, when required by the referencing Code Section, qualification level
- (c) date of examination
- (d) results of examination and related sketches or maps of rejectable indications
- (e) identification of part or component examined

III-892 Performance Demonstration Report 01

Performance demonstrations shall be documented and contain the following information:

- (a) identification of the procedure
- (b) identification of personnel performing and witnessing the qualification
- (c) descriptions and drawings or sketches of the qualification specimen and calibration reference standards, including coating thickness measurement and flaw dimensions
- (d) calibration sensitivity details
- (e) qualification results, including maximum coating thickness and flaws detected

ARTICLE 8 — APPENDIX IV

GLOSSARY OF TERMS FOR EDDY CURRENT EXAMINATION

IV-810 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms related to Eddy Current examination, which appears in Article 8.

IV-820 GENERAL REQUIREMENTS

(a) This standard terminology for nondestructive examination ASTM E 1316 has been adopted by the Committee as SE-1316.

(b) SE-1316 Section 6, Electromagnetic Testing, provides the definitions of terms listed in IV-830(a).

(c) For general terms, such as *Interpretation*, *Flaw*, *Discontinuity*, *Evaluation*, etc., refer to Article 1, Mandatory Appendix I.

(d) Paragraph IV-830(b) provides a list of terms and definitions, which are in addition to SE-1316 and are Code specific.

IV-830 REQUIREMENTS

(a) The following SE-1316 terms are used in conjunction with this Article: *absolute coil*, *differential coils*, *eddy current*, *eddy current testing*, *frequency*, *phase angle*, *probe coil*, *reference standard*, *standard*.

(b) The following Code terms are used in conjunction with this Article.

bobbin coil — for inspection of tubing, a bobbin coil is defined as a circular inside diameter coil wound such that the coil is concentric with a tube during examination

text information — information stored on the recording media to support recorded eddy current data. Examples include tube and steam generator identification, operator's name, date of examination, and results.

unit of data storage — each discrete physical recording medium on which eddy current data and text information are stored. Examples include tape cartridge, floppy disk, etc.

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ARTICLE 9

VISUAL EXAMINATION

01 T-910 SCOPE

(a) This Article contains methods and requirements for visual examination applicable when specified by a referencing Code Section. Specific visual examination procedures required for every type of examination are not included in this Article, because there are many applications where visual examinations are required. Some examples of these applications include nondestructive examinations, leak testing, in-service examinations and fabrication procedures.

(b) The requirements of Article 1, General Requirements, apply when visual examination, in accordance with Article 9, is required by a referencing Code Section.

(c) Definitions of terms for visual examination appear in Article 1, Appendix I – Glossary of Terms in Nondestructive Examination, and Article 9, Appendix I.

TABLE T-923
REQUIREMENTS OF A VISUAL EXAMINATION
PROCEDURE

Requirement (As Applicable)	Essential Variable	Non- Essential Variable
Technique used	X	
Surface Conditions	X	
Surface preparation/cleaning		X
Method or Tool(s) required for Surface Preparation		X
Direct or Indirect Viewing method	X	
Special Illumination	X	
Equipment to be used		X
Sequence of performing examination		X
Data to be documented		X
Report Forms to be Completed		X
Personnel Qualifications	X	
Procedure Qualification Reference	X	

01

T-920 GENERAL

01 T-921 Performance

Visual examination to this Article, when required by the referencing Code Sections, shall be performed to a written procedure prepared by the user.

01 T-922 Personnel Requirements

The user of this Article shall be responsible for assigning qualified personnel to perform visual examinations to the requirements of this Article. At the option of the manufacturer, he may maintain one certification for each product, or several separate signed records based on the area or type of work, or both combined. Where impractical to use specialized visual examination personnel, knowledgeable and trained personnel, having limited qualifications, may be used to perform specific examinations, and to sign the report forms. Personnel performing examinations shall be qualified in accordance with requirements of the referencing Code Section.

T-923 Procedure

01

T-923.1 Requirements. Visual examinations shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in Table T-923. The written procedure shall establish a single value or range of values, for each requirement.

T-923.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement in Table T-923 identified as an essential variable from the specified value, or range of values, shall require requalification of the written procedure. Where a range is specified for an essential variable, the bounding values of the range shall be qualified by demonstration. A change of a requirement identified as a nonessential variable from the specified value, or range of values, does not require requalification of the written procedure. All changes of essential or nonessential variables from the value, or range of values specified by the written

procedure shall require revision of, or an addendum to, the written procedure.

01 T-930 EQUIPMENT

Equipment used for visual examination techniques, for example, direct, remote, or transluscent, shall have the capabilities as specified in the procedure. Capabilities include, but are not limited to viewing, magnifying, identifying, measuring, and/or recording observations in accordance with requirements of the referencing Code Section.

01 T-940 MISCELLANEOUS REQUIREMENTS

01 T-941 Procedure Requirements

The procedure shall contain or reference a report of what was used to demonstrate that the examination procedure was adequate. In general, a fine line $\frac{1}{32}$ in. (0.8 mm) or less in width, an artificial imperfection or a simulated condition, located on the surface or a similar surface to that to be examined, may be considered as a method for procedure demonstration. The condition or artificial imperfection should be in the least discernible location on the area surface to be examined to validate the procedure.

NOTE: T-941.3 is a non-essential variable (See Table T-923).

01 T-941.1 Visual examination shall be performed in accordance with a written procedure.

T-941.2 A written procedure, when required in accordance with T-150, shall include at least the following:

- (a) how visual examination is to be performed;
- (b) type of surface condition and criteria for surface cleaning;
- (c) cleaning instructions or reference to cleaning procedures;
- (d) method or tool for surface preparation, if any;
- (e) whether direct or remote viewing is used;
- (f) special illumination, instruments, or equipment to be used, if any;
- (g) sequence of performing examination, when applicable;
- (h) data to be tabulated, if any;
- (i) report forms or general statement to be completed.

T-941.3 In some instances it is preferable to relate the procedure to a specific component or surface such as the internal examination of a weld many feet from the open end of a tube or tubes of several sizes, but

procedures may be in a general form applicable without adaptation to a variety of unlisted products or situations, thereby reducing the number of written procedures required.

T-941.4 The procedure shall contain or reference a report of what was used to demonstrate that the examination procedure was adequate. In general, a fine line $\frac{1}{32}$ in. (0.8 mm) or less in width, or some other artificial flaw located on the surface or a similar surface to that to be examined, may be considered a test method for this demonstration. The line or artificial flaw should be in the least discernible location on the area examined, to prove the procedure.

T-941.5 Substituting one equipment manufacturer's equipment for another, or changes in the details of test arrangement, will not require requalification.

T-942 Physical Requirements

Personnel shall have an annual vision test to assure natural or corrected near distance acuity such that they are capable of reading standard J-1 letters on standard Jaeger test type charts for near vision. Equivalent near vision tests are acceptable.

T-950 TECHNIQUE

01

T-951 Applications

Visual examination is generally used to determine such things as the surface condition of the part, alignment of mating surfaces, shape, or evidence of leaking. In addition, visual examination is used to determine a composite material's (translucent laminate) subsurface conditions.

T-952 Direct Visual Examination

01

Direct visual examination may usually be made when access is sufficient to place the eye within 24 in. (610 mm) of the surface to be examined and at an angle not less than 30 deg. to the surface to be examined. Mirrors may be used to improve the angle of vision, and aids such as a magnifying lens may be used to assist examinations. Illumination (natural or supplemental white light) for the specific part, component, vessel, or section thereof being examined is required. The minimum light intensity at the examination surface/site shall be 100 footcandles (1000 lux). The light source, technique used, and light level verification is required to be demonstrated one time, documented, and maintained on file. Personnel shall have an annual vision

test to assure natural or corrected near distance acuity such that they are capable of reading standard J-1 letters on standard Jaeger test type charts for near vision. Equivalent near vision tests are acceptable.

T-953 Remote Visual Examination

In some cases, remote visual examination may have to be substituted for direct examination. Remote visual examination may use visual aids such as mirrors, telescopes, borescopes, fiber optics, cameras, or other suitable instruments. Such systems shall have a resolution capability at least equivalent to that obtainable by direct visual observation.

01 T-954 Translucent Visual Examination

Translucent visual examination is a supplement of direct visual examination. The method of translucent visual examination uses the aid of artificial lighting, which can be contained in an illuminator that produces directional lighting. The illuminator shall provide light of an intensity that will illuminate and diffuse the light evenly through the area or region under examination. The ambient lighting must be so arranged that there are no surface glares or reflections from the surface under examination and shall be less than the light applied through the area or region under examination. The artificial light source shall have sufficient intensity to permit "candling" any translucent laminate thickness variations.

T-980 EVALUATION

T-980.1 All examinations shall be evaluated in terms of the acceptance standards of the referencing Code Section.

T-980.2 An examination checklist shall be used to plan visual examination and to verify that the required visual observations were performed. This checklist establishes minimum examination requirements and does not indicate the maximum examination which the Manufacturer may perform in process. **01**

T-990 DOCUMENTATION 01

T-991 Report of Examination 01

T-991.1 A written report of the examination shall contain the following information:

- (a) the date of the examination;
- (b) procedure identification and revision used;
- (c) technique used;
- (d) results of the examination;
- (e) examination personnel identity, and, when required by the referencing Code Section, qualification level;
- (f) identification of the part or component examined.

T-991.2 Even though dimensions, etc., were recorded in the process of visual examination to aid in the evaluation, there need not be documentation of each viewing or each dimensional check. Documentation shall include all observation and dimensional checks specified by the referencing Code Section.

T-992 Performance Documentation 01

Documentation of performance demonstration shall be completed when required by the referencing Code Section.

T-993 Record Maintenance 01

Records shall be maintained as required by the referencing Code Section.

ARTICLE 9

MANDATORY APPENDIX

APPENDIX I — GLOSSARY OF TERMS FOR VISUAL EXAMINATION

I-910 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms related to Visual Examination which appear in Article 9.

01 I-920 GENERAL

(a) Article 30, SE-1316, Section 9, provides the definition of *footcandle (fc)*.

(b) Definitions of terms for visual examination and other methods appear in Article 1, Mandatory Appendix I, Glossary of Terms for Nondestructive Examination.

(c) The following Code terms are used in conjunction with Article 9:

artificial flaw — an intentional imperfection placed on the surface of a material to depict a representative flaw condition

auxiliary lighting — an artificial light source used as a visual aid to improve viewing conditions and visual perception

candling — see *translucent visual examination*

direct visual examination — a visual examination technique performed by eye and without any visual

aids (excluding light source, mirrors, and/or corrective lenses)

enhanced visual examination — a visual examination technique using visual aids to improve the viewing capability, e.g., magnifying aids, borescopes, video probes, fiber optics, etc.

lux (Lx) — a unit of illumination equal to the direct illumination on a surface that is everywhere one meter from a uniform point source of one candle intensity or equal to one lumen per square meter

remote visual examination — a visual examination technique used with visual aids for conditions where the area to be examined is inaccessible for direct visual examination

surface glare — reflections of artificial light that interfere with visual examination

translucent laminate — a series of glass reinforced layers, bonded together, and having capabilities of transmitting light

translucent visual examination — a technique using artificial lighting intensity to permit viewing of translucent laminate thickness variations (also called candling)

visual examination — a nondestructive examination method used to evaluate an item by observation, such as: the correct assembly, surface conditions, or cleanliness of materials, parts, and components used in the fabrication and construction of ASME Code vessels and hardware

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ARTICLE 10

LEAK TESTING

T-1000 INTRODUCTION

01 T-1010 SCOPE

This Article describes methods and requirements for the performance of leak testing.

(a) When a leak testing method or technique of Article 10 is specified by a referencing Code Section, the leak test method or technique shall be used together with Article 1, General Requirements.

(b) Definition of terms used in this Article are in Mandatory Appendix VII of this Article.

(c) The test methods or techniques of these methods can be used for the location of leaks or the measurement of leakage rates.

The Nonmandatory Standards of Article 27 may be used in the preparation of leak test specifications. The specific test method(s) or technique(s) and Glossary of Terms of the methods in this Article are described in Mandatory Appendices I through X and Nonmandatory Appendix A as follows:

Appendix I — Bubble Test — Direct Pressure Technique

Appendix II — Bubble Test — Vacuum Box Technique

Appendix III — Halogen Diode Detector Probe Test
Appendix IV — Helium Mass Spectrometer Test — Detector Probe Technique

Appendix V — Helium Mass Spectrometer Test — Tracer Probe Technique

Appendix VI — Pressure Change Test

Appendix VII — Glossary of Terms

Appendix VIII — Thermal Conductivity Detector Probe Test

Appendix IX — Helium Mass Spectrometer Test — Hood Technique

Appendix X — Ultrasonic Leak Detector Test

Appendix A — Supplementary Leak Testing Formula Symbols

T-1020 GENERAL

01 T-1021 Procedure Requirements

Leak testing shall be performed in accordance with

a written procedure. Each procedure shall include at least the following information, as applicable:

(a) extent of the examination;

(b) type of equipment to be used for detecting leaks or measuring leakage rates;

(c) surface cleanliness preparation and type of equipment used;

(d) method or technique of the test that will be performed;

(e) temperature, pressure, gas, and percent concentration to be used.

T-1022 Referencing Code

For the leak testing method(s) or technique(s) specified by the referencing Code, the referencing Code Section shall then be consulted for the following:

(a) personnel qualification/certification

(b) technique(s)/calibration standards

(c) extent of examination

(d) acceptable test sensitivity or leakage rate

(e) report requirements

(f) retention of records

T-1030 EQUIPMENT

T-1031 Gages

01

(a) *Gage Range.* When dial indicating and recording pressure gage(s) are used in leak testing, they should preferably have the dial(s) graduated over a range of approximately double the intended maximum pressure, but in no case shall the range be less than 1½ nor more than four times that pressure. These range limits do not apply to dial indicating and recording vacuum gages. Range requirements for other types of gages given in an applicable Mandatory Appendix shall be as required by that Appendix.

(b) *Gage Location.* When components are to be pressure/vacuum leak tested, the dial indicating gage(s) shall be connected to the component or to the component from a remote location, with the gage(s) readily visible

to the operator controlling the pressure/vacuum throughout the duration of pressurizing, evacuating, testing, and depressurizing or venting of the component. For large vessels or systems where one or more gages are specified or required, a recording type gage is recommended, and it may be substituted for one of the two or more indicating type gages.

(c) When other types of gage(s) are required by an applicable Mandatory Appendix, they may be used in conjunction with or in place of dial indicating or recording type gages.

01 T-1040 MISCELLANEOUS REQUIREMENTS

T-1041 Cleanliness

The surface areas to be tested shall be free of oil, grease, paint, or other contaminants that might mask a leak. If liquids are used to clean the component or if a hydrostatic or hydropneumatic test is performed before leak testing, the component shall be dry before leak testing.

T-1042 Openings

All openings shall be sealed using plugs, covers, sealing wax, cement, or other suitable material that can be readily and completely removed after completion of the test. Sealing materials shall be tracer gas free.

T-1043 Temperature

The minimum metal temperature for all components during a test shall be as specified in the applicable Mandatory Appendix of this Article or in the referencing Code Section for the hydrostatic, hydropneumatic, or pneumatic test of the pressure component or parts. The minimum or maximum temperature during the test shall not exceed that temperature compatible with the leak testing method or technique used.

T-1044 Pressure/Vacuum (Pressure Limits)

Unless specified in the applicable Mandatory Appendix of this Article or by the referencing Code Section, components that are to be pressure-leak tested shall not be tested at a pressure exceeding 25% of the Design Pressure.

T-1050 PROCEDURE

01

T-1051 Preliminary Leak Test

Prior to employing a sensitive leak testing method, it may be expedient to perform a preliminary test to detect and eliminate gross leaks. This shall be done in a manner that will not seal or mask leaks during the specified test.

T-1052 Test Sequence

01

It is recommended that leak testing be performed before hydrostatic or hydropneumatic testing.

T-1060 CALIBRATION

T-1061 Pressure/Vacuum Gages

(a) All dial indicating and recording type gages used shall be calibrated against a standard deadweight tester, a calibrated master gage, or a mercury column, and recalibrated at least once a year, when in use, unless specified differently by the referencing Code Section or Mandatory Appendix. All gages used shall provide results accurate to within the Manufacturer's listed accuracy and shall be recalibrated at any time that there is reason to believe they are in error.

(b) When other than dial indicating or recording type gages are required by an applicable Mandatory Appendix, they shall be calibrated as required by that Mandatory Appendix or referencing Code Section.

T-1062 Temperature Measuring Devices

When temperature measurement is required by the referencing Code Section or Mandatory Appendix, the device(s) shall be calibrated in accordance with the requirements of that Code Section or Mandatory Appendix.

T-1063 Calibration Leak Standards

T-1063.1 Permeation Type Leak Standard. This standard shall be a calibrated permeation type leak through fused glass or quartz. The standard shall have a helium leakage rate in the range of 1×10^{-6} to 1×10^{-10} std cm³/sec. (1×10^{-7} to 1×10^{-11} Pa m³/s)

01

T-1063.2 Capillary Type Leak Standard. This standard shall be a calibrated capillary type leak through a tube. The standard shall have a leakage rate equal to or smaller than the required test sensitivity times

the actual percent test concentration of the selected tracer gas.

T-1070 TEST

See applicable Mandatory Appendix of this Article.

T-1080 EVALUATION

T-1081 Acceptance Standards

Unless otherwise specified in the referencing Code Section, the acceptance criteria given for each method or technique of that method shall apply. The supplemental leak testing formulas for calculating leakage rates for the method or technique used are stated in the Mandatory Appendices of this Article.

T-1090 DOCUMENTATION

T-1091 Test Report

The test report shall contain, as a minimum, the following information as applicable to the method or technique:

- (a) date of test;
- (b) certification level and name of operator;
- (c) test procedure (number) and revision number;
- (d) test method or technique;
- (e) test results;
- (f) component identification;
- (g) test instrument, standard leak, and material identification;
- (h) test conditions, test pressure, tracer gas, and gas concentration;
- (i) gage(s) — manufacturer, model, range, and identification number;
- (j) temperature measuring device(s) and identification number(s);
- (k) sketch showing method or technique setup.

T-1092 Record Retention

The test report shall be maintained in accordance with the requirements of the referencing Code Section.

ARTICLE 10

MANDATORY APPENDICES

APPENDIX I — BUBBLE TEST — DIRECT PRESSURE TECHNIQUE

I-1000 INTRODUCTION

I-1010 SCOPE

The objective of the direct pressure technique of bubble leak testing is to locate leaks in a pressurized component by the application of a solution or by immersion in liquid that will form bubbles as leakage gas passes through it.

I-1030 EQUIPMENT

I-1031 Gases

Unless otherwise specified, the test gas will normally be air; however, inert gases may be used.

NOTE: When inert gas is used, safety aspects of oxygen deficient atmosphere should be considered.

I-1032 Bubble Solution

(a) The bubble forming solution shall produce a film that does not break away from the area to be tested, and the bubbles formed shall not break rapidly due to air drying or low surface tension. Household soap or detergents are not permitted as substitutes for bubble testing solutions.

(b) The bubble forming solution shall be compatible with the temperature of the test conditions.

I-1033 Immersion Bath

(a) Water or another compatible solution shall be used for the bath.

(b) The immersion solution shall be compatible with the temperature of the test conditions.

I-1070 TEST

I-1071 Soak Time

Prior to examination the test pressure shall be held for a minimum of 15 min.

I-1072 Surface Temperature

As a standard technique, the temperature of the surface of the part to be examined shall not be below 40°F (4°C) nor above 125°F (52°C) throughout the examination. Local heating or cooling is permitted provided temperatures remain within the range of 40°F (4°C) to 125°F (52°C) during examination. Where it is impractical to comply with the foregoing temperature limitations, other temperatures may be used provided that the procedure is demonstrated.

I-1073 Application of Solution

The bubble forming solution shall be applied to the surface to be tested by flowing, spraying, or brushing the solution over the examination area. The number of bubbles produced in the solution by application should be minimized to reduce the problem of masking bubbles caused by leakage.

I-1074 Immersion in Bath

The area of interest shall be placed below the surface of the bath in an easily observable position.

I-1075 Lighting and Visual Aids

When performing the test, the requirements of Article 9, T-952 and T-953 shall apply.

I-1076 Indication of Leakage

The presence of continuous bubble growth on the surface of the material indicates leakage through an orifice passage(s) in the region under examination.

I-1077 Post-Test Cleaning

After testing, surface cleaning may be required for product serviceability.

01 I-1080 EVALUATION**I-1081 Leakage**

Unless otherwise specified by the referencing Code Section, the area under test is acceptable when no continuous bubble formation is observed.

I-1082 Repair/Retest

When leakage is observed, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

**APPENDIX II — BUBBLE TEST —
VACUUM BOX TECHNIQUE****II-1000 INTRODUCTION****II-1010 SCOPE**

The objective of the vacuum box technique of bubble leak testing is to locate leaks in a pressure boundary that cannot be directly pressurized. This is accomplished by applying a solution to a local area of the pressure boundary surface and creating a differential pressure across that local area of the boundary causing the formation of bubbles as leakage gas passes through the solution.

II-1030 EQUIPMENT**II-1031 Bubble Solution**

(a) The bubble forming solution shall produce a film that does not break away from the area to be tested, and the bubbles formed shall not break rapidly due to air drying or low surface tension. The number of bubbles contained in the solution should be minimized to reduce the problem of discriminating between existing bubbles and those caused by leakage.

(b) Soaps or detergents designed specifically for cleaning shall not be used for the bubble forming solution.

(c) The bubble forming solution shall be compatible with the temperature conditions of the test.

II-1032 Vacuum Box

The vacuum box used shall be of convenient size [e.g., 6 in. (152 mm) wide by 30 in. (762 mm) long] and contain a window in the side opposite the open bottom. The open bottom edge shall be equipped with a suitable gasket to form a seal against the test surface. Suitable connections, valves, lighting, and gage shall be provided. The gage shall have a range of 0 psi (0 kPa) to 15 psi (103 kPa), or equivalent pressure units such as 0 in. Hg to 30 in. Hg. The gage range limit requirements of T-1031(a) do not apply.

II-1033 Vacuum Source

The required vacuum can be developed in the box by any convenient method (e.g., air ejector, vacuum pump, or motor intake manifold). The gage shall register a partial vacuum of at least 2 psi (4.1 in. Hg) (13.8 kPa) below atmospheric pressure or the partial vacuum required by the referencing Code Section.

II-1070 TEST**II-1071 Surface Temperature**

As a standard technique, the temperature of the surface of the part to be examined shall not be below 40°F (4°C) nor above 125°F (52°C) throughout the examination. Local heating or cooling is permitted provided temperatures remain in the range of 40°F (4°C) to 125°F (52°C) during the examination. Where it is impractical to comply with the foregoing temperature limitations, other temperatures may be used provided that the procedure is demonstrated.

II-1072 Application of Solution

The bubble forming solution shall be applied to the surface to be tested by flowing, spraying, or brushing the solution over the examination area before placement of the vacuum box.

II-1073 Vacuum Box Placement

The vacuum box shall be placed over the solution coated section of the test surface and the box evacuated to the required partial vacuum.

II-1074 Pressure (Vacuum) Retention

The required partial vacuum (differential pressure) shall be maintained for at least 10 sec examination time.

II-1075 Vacuum Box Overlap

An overlap of 2 in. (51 mm) minimum for adjacent placement of the vacuum box shall be used for each subsequent examination.

II-1076 Lighting and Visual Aids

When performing the test, the requirements of Article 9, T-952 and T-953 shall apply.

II-1077 Indication of Leakage

The presence of continuous bubble growth on the surface of the material or weld seam indicates leakage through an orifice passage(s) in the region under examination.

II-1078 Post-Test Cleaning

After testing, cleaning may be required for product serviceability.

01 II-1080 EVALUATION**II-1081 Leakage**

Unless otherwise specified by the referencing Code Section, the area under test is acceptable when no continuous bubble formation is observed.

II-1082 Repair/Retest

When leakage is observed, the location of the leak(s) shall be marked. The vacuum box shall then be vented and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

APPENDIX III — HALOGEN DIODE DETECTOR PROBE TEST

III-1000 INTRODUCTION

The more sophisticated electronic halogen leak detectors have very high sensitivity. These instruments make possible the detection of halogen gas flow from the

lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures.

III-1010 SCOPE

The halogen detector probe test method is a semiquantitative method used to detect and locate leaks, and shall not be considered quantitative.

**III-1011 Alkali-Ion Diode (Heated Anode)
Halogen Leak Detectors**

The alkali-ion diode halogen detector probe instrument uses the principle of a heated platinum element (anode) and an ion collector plate (cathode), where halogen vapor is ionized by the anode, and the ions are collected by the cathode. A current proportional to the rate of ion formation is indicated on a meter.

**III-1012 Electron Capture Halogen Leak
Detectors**

The electron capture halogen detector probe instrument uses the principle of the affinity of certain molecular compounds for low energy free electrons usually produced by ionization of gas flow through an element with a weak radioactive tritium source. When the gas flow contains halides, electron capture occurs causing a reduction in the concentration of halogen ions present as indicated on a meter. Non-electron capturing nitrogen or argon is used as background gas.

III-1030 EQUIPMENT**III-1031 Tracer Gas**

Gases that may be used are shown in Table III-1031.

III-1031.1 For Alkali-Ion Diode. Halogen leak detectors, select a tracer gas from Table III-1031 that will produce the necessary test sensitivity.

III-1031.2 For Electron Capture. Halogen leak detectors, sulfur hexafluoride, SF₆, is the recommended tracer gas.

III-1032 Instrument

An electronic leak detector as described in III-1011 or III-1012 shall be used. Leakage shall be indicated by one or more of the following signaling devices.

TABLE III-1031
TRACER GASES

Commercial Designation	Chemical Designation	Chemical Symbol
Refrigerant-11	Trichloromonofluoromethane	CCl ₃ F
Refrigerant-12	Dichlorodifluoromethane	CCl ₂ F ₂
Refrigerant-21	Dichloromonofluoromethane	CHCl ₂ F
Refrigerant-22	Chlorodifluoromethane	CHClF ₂
Refrigerant-114	Dichlorotetrafluoroethane	C ₂ Cl ₂ F ₄
Refrigerant-134a	Tetrafluoroethane	C ₂ H ₂ F ₄
Methylene Chloride	Dichloromethane	CH ₂ Cl ₂
Sulfur Hexafluoride	Sulfur Hexafluoride	SF ₆

(a) *Meter* — a meter on the test instrument, or a probe, or both.

(b) *Audio Devices* — a speaker or set of headphones that emits audible indications.

(c) *Indicator Light* — a visible indicator light.

III-1033 Capillary Calibration Leak Standard

A capillary type leak standard per T-1063.2 using 100% tracer gas as selected per III-1031.

III-1060 CALIBRATION

01 III-1061 Standard Leak Size

The maximum leakage rate Q for the leak standard described in III-1033 containing 100% tracer concentration for use in III-1063 shall be calculated as follows:

$$Q = Q_s \frac{\%TG}{100}$$

where Q_s is 1×10^{-4} std cm³/s (1×10^{-5} Pa m³/s), unless specified otherwise by the referencing Code Section, and %TG is the concentration of the tracer gas (in %) that is to be used for the test (See III-1072).

01 III-1062 Warm Up

The detector shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibrating with the leak standard.

01 III-1063 Scanning Rate

The instrument shall be calibrated by passing the probe tip across the orifice of the leak standard in III-

1061. The probe tip shall be kept within $\frac{1}{8}$ in. (3.2 mm) of the orifice of the leak standard. The scanning rate shall not exceed that which can detect leakage rate Q from the leak standard. The meter deflection shall be noted or the audible alarm or indicator light set for this scanning rate.

III-1064 Detection Time

01

The time required to detect leakage from the leak standard is the detection time and it should be observed during system calibration. It is usually desirable to keep this time as short as possible to reduce the time required to pinpoint detected leakage.

III-1065 Frequency and Sensitivity

01

Unless otherwise specified by the referencing Code Section, the sensitivity of the detector shall be determined before and after testing and at intervals of not more than 4 hr during testing. During any calibration check, if the meter deflection, audible alarm, or indicator light indicates that the detector cannot detect leakage from the leak standard of III-1061, the instrument shall be recalibrated and areas tested after the last satisfactory calibration check shall be retested.

III-1070 TEST

III-1071 Location of Test

(a) The test area shall be free of contaminants that could interfere with the test or give erroneous results.

(b) The component to be tested shall, if possible, be protected from drafts or located in an area where drafts will not reduce the required sensitivity of the test.

III-1072 Concentration of Tracer Gas

The concentration of the tracer gas shall be at least 10% by volume at the test pressure, unless otherwise specified by the referencing Code Section.

III-1073 Soak Time

Prior to examination, the test pressure shall be held a minimum of 30 min. When demonstrated, the minimum allowable soak time may be less than that specified above due to the immediate dispersion of the halogen gas when:

(a) a special temporary device (such as a leech box) is used on open components to test short segments;

(b) components are partially evacuated prior to initial pressurization with halogen gas.

III-1074 Scanning Distance

After the required soak time per III-1073, the detector probe tip shall be passed over the test surface. The probe tip shall be kept within $\frac{1}{8}$ in. (3.2 mm) of the test surface during scanning. If a shorter distance is used during calibration, then that distance shall not be exceeded during the examination scanning.

III-1075 Scanning Rate

The maximum scanning rate shall be as determined in III-1063.

III-1076 Scanning Direction

The examination scan should commence in the uppermost portion of the system being leak tested while progressively scanning downward.

01 III-1077 Leakage Detection

Leakage shall be indicated and detected according to III-1032.

III-1078 Application

The following are two examples of applications that may be used (note that other types of applications may be used).

III-1078.1 Tube Examination. To detect leakage through the tube walls when testing a tubular heat exchanger, the detector probe tip should be inserted into each tube end and held for the time period established by demonstration. The examination scan should commence in the uppermost portion of the tubesheet tube rows while progressively scanning downward.

01 III-1078.2 Tube-to-Tubesheet Joint Examination. Tube-to-tubesheet joints may be tested by the encapsulator method. The encapsulator may be a funnel type with the small end attached to the probe tip end and the large end placed over the tube-to-tubesheet joint. If the encapsulator is used, the detection time is determined by placing the encapsulator over the orifice on the leak standard and noting the time required for an indicated instrument response.

III-1080 EVALUATION

III-1081 Leakage

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the allowable rate of 1×10^{-4} std cm³/s (1×10^{-5} Pa m³/s).

III-1082 Repair/Retest

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

APPENDIX IV — HELIUM MASS SPECTROMETER TEST — DETECTOR PROBE TECHNIQUE

IV-1000 INTRODUCTION

IV-1010 SCOPE

This technique describes the use of the helium mass spectrometer to detect minute traces of helium gas in pressurized components. The high sensitivity of this leak detector makes possible the detection of helium gas flow from the lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures, or the determination of the presence of helium in any gaseous mixture. The detector probe is a semiquantitative technique used to detect and locate leaks, and shall not be considered quantitative.

IV-1030 EQUIPMENT

IV-1031 Instrument

A helium mass spectrometer leak detector capable of sensing and measuring minute traces of helium shall be used. Leakage shall be indicated by one or more of the following signaling devices.

(a) *Meter* — a meter on, or attached to, the test instrument.

(b) *Audio Devices* — a speaker or set of headphones that emits audible indications.

(c) *Indicator Light* — a visible indicator light.

IV-1032 Auxiliary Equipment

(a) *Transformer.* A constant voltage transformer shall be used in conjunction with the instrument when line voltage is subject to variations.

(b) *Detector Probe.* All areas to be examined shall be scanned for leaks using a detector probe (sniffer) connected to the instrument through flexible tubing or a hose. To reduce instrument response and clean up time, the tubing or hose length shall be less than 15 ft (4.6 m), unless the test setup is specifically designed to attain the reduced response and clean up time for longer tubing or hose lengths.

IV-1033 Calibration Leak Standards

Calibration leak standards may be either a permeation or capillary type standard per T-1063.1 and T-1063.2. The type of leak standard used shall be established by the instrument or system sensitivity requirement, or as specified by the referencing Code Section.

IV-1060 CALIBRATION**IV-1061 Instrument Calibration**

IV-1061.1 Warm Up. The instrument shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibrating with the calibrated leak standard.

- 01 **IV-1061.2 Calibration.** Calibrate the helium mass spectrometer per the instrument's manufacturer's operation and maintenance manual, using a permeation type leak standard as stated in T-1063.1 to establish that the instrument is at optimum or adequate sensitivity. The instrument shall have a sensitivity of at least 1×10^{-9} std cm³/s (1×10^{-10} Pa m³/s) for helium.

IV-1062 System Calibration

- 01 **IV-1062.1 Standard Leak Size.** The maximum leakage rate Q for the leak standard described in IV-1033, containing 100% helium concentration for use in IV-1062.2, shall be calculated as follows:

$$Q = Q_s \frac{\%TG}{100}$$

where Q_s is 1×10^{-4} std cm³/s (1×10^{-5} Pa m³/s), unless specified otherwise by the referencing Code Section, and %TG is the concentration of the tracer

gas (in %) that is to be used for the test (See IV-1072).

IV-1062.2 Scanning Rate. After connecting the detector probe to the instrument, the system shall be calibrated by passing the detector probe tip across the orifice of the leak standard in IV-1062.1. The probe tip shall be kept within $\frac{1}{8}$ in. (3.2 mm) of the orifice of the leak standard. The scanning rate shall not exceed that which can detect leakage rate Q from the leak standard. The meter deflection shall be noted the audible alarm or indicator light set for this scanning rate.

IV-1062.3 Detection Time. The time required to detect leakage from the leak standard is the detection time, and it should be observed during system calibration. It is usually desirable to keep this time as short as possible to reduce the time required to pinpoint detected leakage.

IV-1062.4 Frequency and Sensitivity. Unless otherwise specified by the referencing Code Section, the system sensitivity shall be determined before and after testing and at intervals of not more than 4 hr during the test. During any calibration check, if the meter deflection, audible alarm, or visible light indicates that the system cannot detect leakage per IV-1062.2, the system, and if necessary, the instrument, shall be recalibrated and all areas tested after the last satisfactory calibration check shall be retested.

IV-1070 TEST**IV-1071 Location of Test**

The component to be tested shall, if possible, be protected from drafts or located in an area where drafts will not reduce the required sensitivity of the test.

IV-1072 Concentration of Tracer Gas

The concentration of the helium tracer gas shall be at least 10% by volume at the test pressure, unless otherwise specified by the referencing Code Section.

IV-1073 Soak Time

Prior to testing, the test pressure shall be held a minimum of 30 min. The minimum allowable soak time may be less than that specified above due to the immediate dispersion of the helium gas when:

(a) a special temporary device (such as a leech box) is used on open components to test short segments;

(b) components are partially evacuated prior to initial pressurization with helium gas.

IV-1074 Scanning Distance

After the required soak time per IV-1073, the detector probe tip shall be passed over the test surface. The probe tip shall be kept within $\frac{1}{8}$ in. (3.2 mm) of the test surface during scanning. If a shorter distance is used during system calibration, then that distance shall not be exceeded during test scanning.

IV-1075 Scanning Rate

The maximum scanning rate shall be as determined in IV-1062.2.

IV-1076 Scanning Direction

The examination scan should commence in the lowermost portion of the system being tested while progressively scanning upward.

01 IV-1077 Leakage Detection

Leakage shall be indicated and detected according to IV-1031.

IV-1078 Application

The following are two examples of applications that may be used (note that other types of applications may be used).

IV-1078.1 Tube Examination. To detect leakage through the tube walls when testing a tubular heat exchanger, the detector probe tip should be inserted into each tube end and held for the time period established by demonstration. The examination scan should commence in the lowermost portion of the tubesheet tube rows while progressively scanning upward.

01 IV-1078.2 Tube-to-Tubesheet Joint Examination. Tube-to-tubesheet joints may be tested by the encapsulator method. The encapsulator may be a funnel type with the small end attached to the probe tip end and the large end placed over the tube-to-tubesheet joint. If the encapsulator is used, the detection time is determined by placing the encapsulator over the orifice on the leak standard and noting the time required for an indicated instrument response.

IV-1080 EVALUATION

01

IV-1081 Leakage

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the allowable rate of 1×10^{-4} std cm³/s (1×10^{-5} Pa m³/s).

IV-1082 Repair/Retest

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

APPENDIX V — HELIUM MASS SPECTROMETER TEST — TRACER PROBE TECHNIQUE

01

V-1010 SCOPE

01

This technique describes the use of the helium mass spectrometer to detect minute traces of helium gas in evacuated components.

The high sensitivity of this leak detector, when tracer probe testing, makes possible the detection and location of helium gas flow from the higher pressure side of very small openings through the evacuated envelope or barrier separating the two regions at different pressures. This is a semiquantitative technique and shall not be considered quantitative.

V-1030 EQUIPMENT

V-1031 Instrument

01

A helium mass spectrometer leak detector capable of sensing and measuring minute traces of helium shall be used. Leakage shall be indicated by one or more of the following signaling devices.

(a) *Meter* — a meter on or attached to the test instrument.

(b) *Audio Devices* — a speaker or set of headphones that emits audible indications.

(c) *Indicator Light* — a visible indicator light.

01 V-1032 Auxiliary Equipment

(a) *Transformer.* A constant voltage transformer shall be used in conjunction with the instrument when line voltage is subject to variations.

(b) *Auxiliary Pump System.* When the size of the test system necessitates the use of an auxiliary vacuum pump system, the ultimate absolute pressure and pump speed capability of that system shall be sufficient to attain required test sensitivity and response time.

(c) *Manifold.* A system of pipes and valves with proper connections for the instrument gages, auxiliary pump, calibration leak standard, and test component.

(d) *Tracer Probe.* Tubing connected to a source of 100% helium with a valved fine opening at the other end for directing a fine stream of helium gas.

(e) *Vacuum Gage(s).* The range of vacuum gage(s) capable of measuring the absolute pressure at which the evacuated system is being tested. The gage(s) for large systems shall be located on the system as far as possible from the inlet to the pump system.

01 V-1033 Calibration Leak Standard

A capillary type leak standard per T-1063.2 with a maximum helium leakage rate of 1×10^{-5} std cm^3/s (1×10^{-6} Pa m^3/s) shall be used unless otherwise specified by the referencing Code Section.

V-1060 CALIBRATION

V-1061 Instrument Calibration

V-1061.1 Warm Up. The instrument shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibrating with the calibration leak standard.

- 01 **V-1061.2 Calibration.** Calibrate the helium mass spectrometer per the instrument's manufacturer's operation and maintenance manual, using a permeation type leak standard as stated in T-1063.1 to establish that the instrument is at optimum or adequate sensitivity. The instrument shall have a sensitivity of at least 1×10^{-9} std cm^3/s (1×10^{-10} Pa m^3/s) for helium.

V-1062 System Calibration

- 01 **V-1062.1 Standard Leak Size.** The calibrated leak standard, as stated in V-1033, shall be attached to the component as far as possible from the instrument connection to the component. The leak standard shall remain open during system calibration.

V-1062.2 Scanning Rate. With the component evacuated to an absolute pressure sufficient for connection of the helium mass spectrometer to the system, the system shall be calibrated for the test by passing the tracer probe tip across the orifice of the leak standard. The probe tip shall be kept within $\frac{1}{4}$ in. (6 mm) of the orifice of the leak standard. For a known flow rate from the tracer probe of 100% helium, the scanning rate shall not exceed that which can detect leakage through the calibration leak standard into the test system.

V-1062.3 Detection Time. The time required to detect leakage from the leak standard is the detection time, and it should be observed during system calibration. It is desirable to keep this time as short as possible to reduce the time required to pinpoint detected leakage.

V-1062.4 Frequency and Sensitivity. Unless otherwise specified by the referencing Code Section, the system sensitivity shall be determined before and after testing and at intervals of not more than 4 hr during testing. During any calibration check, if the meter deflection, audible alarm, or visible light indicates that the system cannot detect leakage per V-1062.2, the system, and if necessary, the instrument, shall be recalibrated and all areas tested after the last satisfactory calibration check shall be retested.

V-1062.5 Hood Technique. A calibrated leak CL standard as per T-1063.1 with 100% helium shall be attached, where feasible, to the component as far as possible from the instrument connection to the component. The calibrated leak standard shall remain open during system calibration until the response time has been determined.

(a) *Evacuation.* With the component evacuated to an absolute pressure sufficient for connection of the helium mass spectrometer to the system, the calibrated leak standard shall be opened to the system. The calibrated leak standard shall remain open until the instrument signal becomes stable, and the response time has been determined.

(b) *Response Time.* The time is recorded when the calibrated leak standard is opened to the component and when the increase in output signal becomes stable. The elapsed time between the two readings is the response time. The stable instrument reading shall be noted and recorded as M_1 in divisions.

(c) *Background Reading.*¹ Background M_2 in divisions is established after determining response time. The calibration leak standard is closed to the system

¹ System background noise. For definition of symbols, see Nonmandatory Appendix A.

and the instrument reading shall be recorded when it becomes stable.

(d) *Preliminary Calibration.* The preliminary system sensitivity shall be calculated as follows:

$$S_1 = \frac{CL}{M_1 - M_2} = \text{std cm}^3/\text{sec}/\text{div}$$

The calibration shall be repeated when there is any change in the leak detector setup (e.g., a change in the portion of helium bypassed to the auxiliary pump, if used) or any change in the calibrated leak. The calibrated leak standard shall be isolated from the system upon completing the preliminary system sensitivity calibration.

(e) *Final Calibration.* Upon completing the test of the system, and with the component still under the hood, the instrument output reading M_3 shall be determined with the calibrated leak closed. Again, the calibrated leak shall be opened into the system being tested. The increase in instrument output M_4 shall be used in calculating the final system sensitivity as follows:

$$S_2 = \frac{CL}{M_4 - M_3} \text{ std cm}^3/\text{sec}/\text{div}$$

If the final system sensitivity S_2 has decreased below the initial system sensitivity S_1 by more than 35%, the instrument shall be cleaned and/or repaired, recalibrated and the component or system retested.

(f) *Measured Leakage Rate.* The measured leakage rate of the component shall be determined as follows:

$$Q_1 = S_2(M_3 - M_2) \text{ std cm}^3/\text{sec}$$

(g) *Actual Leakage Rate.* Calculation of actual leakage rate (corrected for tracer gas concentration used):

$$Q_2 = \frac{Q_1 \times 100}{\% \text{ He}} \text{ std cm}^3/\text{sec}$$

V-1070 TEST

01 V-1071 Scanning Rate

The maximum scanning rate shall be as determined in V-1062.2.

V-1072 Scanning Direction

01

The examination scan should commence in the uppermost portion of the system being tested while progressively scanning downward.

V-1073 Scanning Distance

01

The tracer probe tip shall be kept within $\frac{1}{4}$ in. (6 mm) of the test surface during scanning. If a shorter distance is used during system calibration, then that distance shall not be exceeded during the examination scanning.

V-1074 Leakage Detection

01

Leakage shall be indicated and detected according to V-1031.

V-1075 Flow Rate

01

The minimum flow rate shall be as set in V-1062.2.

V-1080 EVALUATION

01

V-1081 Leakage

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the allowable rate of 1×10^{-5} std cm³/s (1×10^{-6} Pa m³/s).

V-1082 Repair/Retest

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be vented, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

APPENDIX VI — PRESSURE CHANGE TEST

VI-1010 SCOPE

This test method describes the techniques for determining the leakage rate of the boundaries of a closed component or system at a specific pressure or vacuum. Pressure hold, absolute pressure, maintenance of pressure, pressure loss, pressure decay, pressure rise, and vacuum retention are examples of techniques that may be used whenever pressure change testing is specified

as a means of determining leakage rates. The tests specify a maximum allowable change in either pressure per unit of time, percentage volume, or mass change per unit of time.

VI-1020 GENERAL

Each of the tests shall be performed by either pneumatic pressurization or evacuation of a closed component or system to a specific pressure or vacuum. Temperature, pressure, or vacuum are systematically recorded for a specified period of time. Analysis of data determines the component or system acceptability with respect to leakage rate or pressure change per unit of time.

VI-1030 EQUIPMENT

VI-1031 Pressure Measuring Instruments

(a) *Gage Range.* Dial indicating and recording type gages shall meet the requirements of T-1031(a). Liquid manometers or quartz Bourdon tube gages may be used over their entire range.

(b) *Gage Location.* The location of the gage(s) shall be that stated in T-1031(b).

(c) *Types of Gages.* Regular or absolute gages may be used in pressure change testing. When greater accuracy is required, quartz Bourdon tube gages or liquid manometers may be used. The gage(s) used shall have an accuracy, resolution, and repeatability compatible with the acceptance criteria.

VI-1032 Temperature Measuring Instruments

Dry bulb or dew point temperature measuring instruments, when used, shall have accuracy, repeatability, and resolution compatible with the leakage rate acceptance criteria.

VI-1060 CALIBRATION

VI-1061 Pressure Measuring Instruments

All dial indicating, recording, and quartz Bourdon tube gages shall be calibrated per T-1061(b). The scale of liquid manometers shall be calibrated against standards that have known relationships to national standards, where such standards exist.

VI-1062 Temperature Measuring Instruments

Calibration for dry bulb and dew point temperature measuring instruments shall be against standards that have known relationships to national standards, where such standards exist.

VI-1070 TEST

VI-1071 Pressure Application

Components that are to be tested above atmospheric pressure shall be pressurized per T-1044.

VI-1072 Vacuum Application

Components that are to be tested under vacuum shall be evacuated to at least 2 psi (4.1 in. Hg) (13.8 kPa) below atmospheric pressure or as required by the referencing Code Section.

VI-1073 Test Duration

The test pressure (or vacuum) shall be held for the duration specified by the referencing Code Section or, if not specified, it shall be sufficient to establish the leakage rate of the component system within the accuracy or confidence limits required by the referencing Code Section. For very small components or systems, a test duration in terms of minutes may be sufficient. For large components or systems, where temperature and water vapor corrections are necessary, a test duration in terms of many hours may be required.

VI-1074 Small Pressurized Systems

For temperature stabilization of very small pressurized systems, such as gasket interspaces, where only system (metal) temperature can be measured, at least 15 min shall elapse after completion of pressurization and before starting the test.

VI-1075 Large Pressurized Systems

For temperature stabilization of large pressurized systems where the internal gas temperature is measured after completion of pressurization, it shall be determined that the temperature of the internal gas has stabilized before starting the test.

VI-1076 Start of Test

At the start of the test, initial temperature and pressure (or vacuum) readings shall be taken and thereafter at regular intervals, not to exceed 60 min, until the end of the specified test duration.

VI-1077 Essential Variables

(a) When it is required to compensate for barometric pressure variations, measurement of the test pressure shall be made with either an absolute pressure gage or a regular pressure gage and a barometer.

(b) When it is required by the referencing Code Section, or when the water vapor pressure variation can significantly affect the test results, the internal dew point temperature or relative humidity shall be measured.

VI-1080 EVALUATION**VI-1081 Acceptable Test**

When the pressure change or leakage rate is equal to or less than that specified by the referencing Code Section, the test is acceptable.

VI-1082 Rejectable Test

When the pressure change or leakage rate exceeds that specified by the referencing Code Section, the results of the test are unsatisfactory. Leak(s) may be located by other methods described in the Mandatory Appendices. After the cause of the excessive pressure change or leakage rate has been determined and repaired in accordance with the referencing Code Section, the original test shall be repeated.

NOTE: For more information regarding this method of testing refer to the following:

(a) 10 CFR 50, Appendix J, *Primary Containment Leakage Testing for Water Cooled Power Reactors*.

(b) ANSI/ANS 56.8-1981, *American National Standard Containment System Leakage Testing Requirements*, published by the American Nuclear Society.

APPENDIX VII — GLOSSARY OF TERMS FOR LEAK TESTING

VII-1010 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms which appear in Article 10, Leak Testing.

VII-1020 GENERAL

01

(a) ASTM E 1316, Standard Terminology for Nondestructive Examinations, has been adopted by the Committee as SE-1316.

(b) SE-1316 Section 8 provides the definitions of terms listed in (e).

(c) For general terms such as *Discontinuity*, *Evaluation*, *Flaw*, *Indication*, *Inspection*, etc., refer to Article 1, Mandatory Appendix I.

(d) The following SE-1316 terms are used in conjunction with this Article: *absolute pressure*; *background signal*; *gage pressure*; *gas*; *halogen*; *halogen leak detector*; *hood test*; *leak*; *leakage rate*; *leak testing*; *mass spectrometer*; *mass spectrometer leak detector*; *sampling probe*; *standard leak*; *tracer gas*; *vacuum*.

(e) The following Code terms, which are in addition to SE-1316, and are Code specific, are used in conjunction with this Article.

background reading — see *background signal* in (d)

calibration leak standard — see *standard leak* in (d)

detector probe — see *sampling probe* in (d)

dew point temperature — that temperature at which the gas in a system would be capable of holding no more water vapor and condensation in the form of dew would occur

dry bulb temperature — the ambient temperature of the gas in a system

halogen diode detector — see *halogen leak detector* in (d)

helium mass spectrometer — see *mass spectrometer* and *mass spectrometer leak detector* in (d)

hood technique — see *hood test* in (d)

immersion bath — a low surface tension liquid into which a gas containing enclosure is submerged to detect leakage which forms at the site or sites of a leak or leaks

immersion solution — see *immersion bath*

inert gas — a gas that resists combining with other substances. Examples are helium, neon, and argon.

instrument calibration — introduction of a known size standard leak into an isolated leak detector for the purpose of determining the smallest size leakage rate of a particular gas at a specific pressure and temperature that the leak detector is capable of indicating for a particular division on the leak indicator scale

leakage — the fluid, either liquid or gas, flowing through a leak and expressed in units of mass flow; i.e., pressure and volume per time

leak standard — see *standard leak* in (d)

quartz Bourdon tube gage — this high accuracy gage is a servonulling differential pressure measuring electronic instrument. The pressure transducing element is a one piece fused quartz Bourdon element.

regular pressure — see *gage pressure* in (d)
sensitivity — the size of the smallest leakage rate that can be unambiguously detected by the leak testing instrument, method, or technique being used

soak time — the elapsed time between when the desired differential pressure is attained on a system and the time when the test technique is performed to detect leakage or measure leakage rate

standard dead weight tester — a device for hydraulically balancing the pressure on a known high accuracy weight against the reading on a pressure gage for the purpose of calibrating the gage

system calibration — introduction of a known size standard leak into a test system with a leak detector for the purpose of determining the smallest size leakage rate of a particular gas at a specific pressure and temperature that the leak detector as part of the test system is capable of indicating for a particular division on the leak indicator scale

thermal conductivity detector — a leak detector that responds to differences in the thermal conductivity of a sampled gas and the gas used to zero it (i.e., background atmosphere)

vacuum box — a device used to obtain a pressure differential across a weld that cannot be directly pressurized. It contains a large viewing window, special easy seating and sealing gasket, gage, and a valved connection for an air ejector, vacuum pump, or intake manifold

water vapor — gaseous form of water in a system

APPENDIX VIII — THERMAL CONDUCTIVITY DETECTOR PROBE TEST

VIII-1000 INTRODUCTION

These instruments make possible the detection of a tracer gas flow from the lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures.

VIII-1010 SCOPE

The thermal conductivity detector probe test method is a semiquantitative method used to detect and locate leaks, and shall not be considered quantitative.

VIII-1011 Thermal Conductivity Leak Detectors

The thermal conductivity detector probe instrument uses the principle that the thermal conductivity of a gas or gas mixture changes with any change in the

TABLE VIII-1031
TRACER GASES

Designation	Chemical Designation	Chemical Symbol
...	Helium	He
...	Argon	Ar
...	Carbon Dioxide	CO ₂
Refrigerant-11	Trichloromonofluoromethane	CCl ₃ F
Refrigerant-12	Dichlorodifluoromethane	CCl ₂ F ₂
Refrigerant-21	Dichloromonofluoromethane	CHCl ₂ F
Refrigerant-22	Chlorodifluoromethane	CHClF ₂
Refrigerant-114	Dichlorotetrafluoroethane	C ₂ Cl ₂ F ₄
Refrigerant-134a	Tetrafluoroethane	C ₂ H ₂ F ₄
Methylene Chloride	Dichloromethane	CH ₂ Cl ₂
Sulfur Hexafluoride	Sulfur Hexafluoride	SF ₆

concentration(s) of the gas or gas mixture (i.e., the introduction of a tracer gas in the area of a leak).

VIII-1030 EQUIPMENT

VIII-1031 Tracer Gas

In principle, any gas having a thermal conductivity different from air can be used as a tracer gas. The sensitivity achievable depends on the relative differences of the thermal conductivity of the gases [i.e., background air (air used to zero the instrument) and the sampled air (air containing the tracer gas) in the area of a leak]. Table VIII-1031 lists some of the typical tracer gases used. The tracer gas to be used shall be selected based on the required test sensitivity.

VIII-1032 Instrument

An electronic leak detector as described in VIII-1011 shall be used. Leakage shall be indicated by one or more of the following signaling devices:

(a) *Meter*. A meter on the test instrument, or a probe, or both.

(b) *Audio Devices*. A speaker or sets of headphones that emit(s) audible indications.

(c) *Indicator Light*. A visible indicator light.

VIII-1033 Capillary Calibration Leak Standard

A capillary type leak standard per T-1063.2 using 100% tracer gas as selected per VIII-1031.

VIII-1060 CALIBRATION**01 VIII-1061 Standard Leak Size**

The maximum leakage rate Q for the leak standard described in VIII-1033 containing 100% tracer concentration for use in VIII-1063 shall be calculated as follows:

$$Q = Q_s \frac{\% TG}{100}$$

where Q_s [in std cm³/s (Pa m³/s)] is the required test sensitivity and %TG is the concentration of the tracer gas (in %) that is to be used for the test. See VIII-1072.

01 VIII-1062 Warm-up

The detector shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibrating with the leak standard.

01 VIII-1063 Scanning Rate

The detector shall be calibrated by passing the probe tip across the orifice of the leak standard in VIII-1061. The probe tip shall be kept within $\frac{1}{2}$ in. (13 mm) of the orifice of the leak standard. The scanning rate shall not exceed that which can detect leakage rate Q from the leak standard. The meter deflection shall be noted or the audible alarm or indicator light set for this scanning rate.

01 VIII-1064 Detection Time

The time required to detect leakage from the leak standard is the detection time and it should be observed during system calibration. It is usually desirable to keep this time as short as possible to reduce the time required to pinpoint detected leakage.

01 VIII-1065 Frequency and Sensitivity

Unless otherwise specified by the referencing Code Section, the sensitivity of the detector shall be determined before and after testing and at intervals of not more than 4 hr during testing. During any calibration check, if the meter deflection, audible alarm, or indicator light indicate that the detector cannot detect leakage per VIII-1063, the instrument shall be recalibrated and areas tested after the last satisfactory calibration check shall be retested.

VIII-1070 TEST**VIII-1071 Location of Test**

(a) The test area shall be free of contaminants that could interfere with the test or give erroneous results.

(b) The component to be tested shall, if possible, be protected from drafts or located in an area where drafts will not reduce the required sensitivity of the test.

VIII-1072 Concentration of Tracer Gas

The concentration of the tracer gas shall be at least 10% by volume at the test pressure, unless otherwise specified by the referencing Code Section.

VIII-1073 Soak Times

Prior to examination, the test pressure shall be held a minimum of 30 min. When demonstrated, the minimum allowable soak time may be less than that specified above due to the immediate dispersion of the tracer gas when:

(a) a special temporary device (such as a leech box) is used on open components to test short segments;

(b) components are partially evacuated prior to initial pressurization with tracer gas.

VIII-1074 Scanning Distance

After the required soak time per VIII-1073, the detector probe tip shall be passed over the test surface. The probe tip shall be kept within $\frac{1}{2}$ in. (13 mm) of the test surface during scanning. If a shorter distance is used during calibration, then that distance shall not be exceeded during the examination scanning.

VIII-1075 Scanning Rate

The maximum scanning rate shall be as determined in VIII-1063.

VIII-1076 Scanning Direction

For tracer gases that are lighter than air, the examination scan should commence in the lowermost portion of the system being tested while progressively scanning upward. For tracer gases that are heavier than air, the examination scan should commence in the uppermost portion of the system being tested while progressively scanning downward.

01 VIII-1077 Leakage Detection

Leakage shall be indicated and detected according to VIII-1032.

VIII-1078 Application

The following are two examples of applications that may be used (note that other types of applications may be used).

VIII-1078.1 Tube Examination. To detect leakage through the tube walls when testing a tubular heat exchanger, the detector probe tip should be inserted into each tube and held for the time period established by demonstration.

01 VIII-1078.2 Tube-to-Tubesheet Joint Examination. Tube-to-tubesheet joints may be tested by the encapsulator method. The encapsulator may be a funnel type with the small end attached to the probe tip end and the large end placed over the tube-to-tubesheet joint. If the encapsulator is used, the detection time is deter-

mined by placing the encapsulator over the orifice on the leak standard and noting the time required for an indicated instrument response.

VIII-1080 EVALUATION**01****VIII-1081 Leakage**

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the maximum leakage rate Q , determined per VIII-1061.

VIII-1082 Repair/Retest

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

ARTICLE 10 — APPENDIX IX

HELIUM MASS SPECTROMETER TEST — HOOD TECHNIQUE

IX-1010 SCOPE

This technique describes the use of the helium mass spectrometer to respectively detect and measure minute traces of helium gas in evacuated components.

The high sensitivity of this leak detector, when hood testing, makes possible the detection and measurement of total helium gas flow from the higher pressure side of all hooded, very small openings through the evacuated envelope or barrier that separates the two regions at different pressures. This is a quantitative measurement technique.

IX-1030 EQUIPMENT

IX-1031 Instrument

A helium mass spectrometer leak detector capable of sensing and measuring minute traces of helium shall be used. Leakage shall be indicated by a meter on or attached to the test instrument.

IX-1032 Auxiliary Equipment

(a) *Transformer.* A constant voltage transformer shall be used in conjunction with the instrument when line voltage is subject to variations.

(b) *Auxiliary Pump System.* When the size of the test system necessitates the use of an auxiliary vacuum pump system, the ultimate absolute pressure and pump speed capability of that system shall be sufficient to attain required test sensitivity and response time.

(c) *Manifold.* A system of pipes and valves with proper connections for the instrument gages, auxiliary pump, calibration leak standard, and test component.

(d) *Hood.* Any suitable envelope or container, such as a plastic bag, with a through aperture for the manifold.

(e) *Vacuum Gage(s).* The range of vacuum gage(s) capable of measuring the absolute pressure at which

the evacuated system is being tested. The gage(s) for large systems shall be located on the system as far as possible from the inlet to the pump system.

IX-1033 Calibration Leak Standard

A permeation type leak standard per T-1063.1 with a maximum helium leakage rate of 1×10^{-6} std cm³/s (1×10^{-7} Pa m³/s) shall be used, unless specified otherwise by the referencing Code Section.

IX-1050 TECHNIQUE

IX-1051 Permeation

When systems with long response times (i.e., low helium mass spectrometer throughput) are to be tested, helium permeation through nonmetallic seals can lead to false results. In cases like this, it is recommended, if possible, to locally hood test such seals or exclude them from the hood if the seals are not required to be tested.

IX-1052 Repetitive or Similar Tests

For repetitive tests or where the test time is known from previous similar tests, the preliminary calibration, per IX-1062.4, may be omitted.

IX-1060 CALIBRATION

IX-1061 Instrument Calibration

IX-1061.1 Warm Up. The instrument shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibrating with the leak standard.

IX-1061.2 Calibration. Calibrate the helium mass spectrometer per the instrument manufacturer's operation and maintenance manual using a permeation type

leak standard as stated in T-1063.1 to establish that the instrument is at optimum or adequate sensitivity. The instrument shall have sensitivity of at least 1×10^{-9} std cm³/s (1×10^{-10} Pa m³/s) for helium.

IX-1062 System Calibration

IX-1062.1 Standard Leak Size. A calibrated leak *CL* standard as per T-1063.1 with 100% helium shall be attached, where feasible, to the component as far as possible from the instrument connection to the component.

IX-1062.2 Response Time. With the component evacuated to an absolute pressure sufficient for connection of the helium mass spectrometer to the system, the system shall be calibrated by opening the leak standard to the system. The leak standard shall remain open until the instrument signal becomes stable.

The time shall be recorded when the leak standard is first opened to the component and again when the increase in output signal becomes stable. The elapsed time between the two readings is the response time. The stable instrument reading shall be noted and recorded as M_1 in divisions.

IX-1062.3 Background Reading.¹ Background M_2 in divisions is established after determining response time. The leak standard shall be closed to the system and the instrument reading shall be recorded when it becomes stable.

IX-1062.4 Preliminary Calibration. The preliminary system sensitivity shall be calculated as follows:

$$S_1 = \frac{CL}{M_1 - M_2} = \text{std cm}^3/\text{s}/\text{div (Pa m}^3/\text{s}/\text{div)}$$

The calibration shall be repeated when there is any change in the leak detector setup (e.g., a change in the portion of helium bypassed to the auxiliary pump, if used) or any change in the leak standard. The leak standard shall be isolated from the system upon completing the preliminary system sensitivity calibration.

IX-1062.5 Final Calibration. Upon completing the test of the system per IX-1071.4, and with the component still under the hood, the leak standard shall be again opened into the system being tested. The increase in instrument output shall be noted and recorded as

¹ System background noise. For definition of symbols, see Nonmandatory Appendix A.

M_4 in divisions and used in calculating the final system sensitivity as follows:

$$S_2 = \frac{CL}{M_4 - M_3} = \text{std cm}^3/\text{s}/\text{div (Pa m}^3/\text{s}/\text{div)}$$

If the final system sensitivity S_2 has decreased below the preliminary system sensitivity S_1 by more than 35%, the instrument shall be cleaned and/or repaired, recalibrated, and the component retested.

IX-1070 TEST

IX-1071 Standard Technique

IX-1071.1 Hood. For a single wall component or part, the hood (envelope) container may be made of a material such as plastic.

IX-1071.2 Filling of Hood with Tracer Gas. After completing preliminary calibration per IX-1062.4, the space between the component outer surface and the hood shall be filled with helium.

IX-1071.3 Estimating or Determining Hood Tracer Gas Concentration. The tracer gas concentration in the hood enclosure shall be determined or estimated.

IX-1071.4 Test Duration. After filling the hood with helium, the instrument output M_3 in divisions shall be noted and recorded after waiting for a test time equal to the response time determined in IX-1062.2 or, if the output signal has not become stable, until the output signal stabilizes.

IX-1071.5 System Measured Leakage Rate. After completing final calibration per IX-1062.5, the system leakage rate shall be determined as follows:

(a) For tests where no change in output signal occurs (i.e., $M_2 = M_3$), the system leakage rate shall be reported as being “below the detectable range of the system” and the item under test passes.

(b) For tests where the output signal (M_3) remains on scale, the leakage rate shall be determined as follows:

$$Q = \frac{S_2 (M_3 - M_2) \times 100}{\%TG} \text{ std cm}^3/\text{s (Pa m}^3/\text{s)}$$

where %TG is the concentration of the tracer gas (in %) in the hood. See IX-1071.3.

(c) For tests where the output signal (M_3) exceeds the detectable range of the system (i.e., output signal is off scale), the system leakage rate shall be reported

as being “greater than the detectable range of the system” and the item under test fails.

IX-1072 Alternative Technique

IX-1072.1 System Correction Factor. For helium mass spectrometer leak indicator meters in leakage rate units, a System Correction Factor (SCF) may be utilized if it is desired to utilize the actual indicator meter leakage rate units in lieu of converting the readings to divisions [e.g., the values of M_1 , M_2 , M_3 , and M_4 are directly read from the helium mass spectrometer in std cm³/s (Pa m³/s)].

IX-1072.2 Alternative Formulas. The following formulas shall be used in lieu of those described in IX-1062:

(a) *Preliminary Calibration (per IX-1062.4).* The preliminary system correction factor (PSCF) shall be calculated as follows:

$$PSCF = CL / (M_1 - M_2)$$

(b) *Final Calibration (per IX-1062.5).* The final system correction factor (FSCF) shall be calculated as follows:

$$FSCF = CL / (M_4 - M_3)$$

If the FSCF has decreased below the PSCF by more than

35%, the instrument shall be cleaned and/or repaired, recalibrated, and the component retested.

(c) *System Measured Leakage Rate (per IX-1071.5).* The system leakage rate shall be determined as follows:

$$Q = \frac{(FSCF \times M_3) \times 100}{\%TG} \text{ std cm}^3/\text{s (Pa m}^3/\text{s)}$$

IX-1080 EVALUATION

Unless otherwise specified by the referencing Code Section, the component tested is acceptable when the measured leakage rate Q is equal to or less than 1×10^{-6} std cm³/s (1×10^{-7} Pa m³/s) of helium.

IX-1081 Leakage

When the leakage rate exceeds the permissible value, all welds or other suspected areas shall be retested using a tracer probe technique. All leaks shall be marked and temporarily sealed to permit completion of the tracer probe retest. The temporary seals shall be of a type which can be readily and completely removed after testing has been completed.

IX-1082 Repair/Retest

The component shall then be vented and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

ARTICLE 10 — APPENDIX X

ULTRASONIC LEAK DETECTOR TEST

X-1000 INTRODUCTION

This technique describes the use of an ultrasonic leak detector to detect the ultrasonic energy produced by the flow of a gas from the lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures.

(a) Due to the low sensitivity [maximum sensitivity of 10^{-2} std cm³/s (10^{-3} Pa m³/s)] of this technique, it should not be utilized for the acceptance testing of vessels that will contain lethal or hazardous substances.

(b) This is a semiquantitative method used to detect and locate leaks and shall not be considered quantitative.

X-1020 GENERAL

X-1021 Written Procedure Requirements

X-1021.1 Requirements. Ultrasonic leak testing shall be performed in accordance with a written procedure which shall, as a minimum, contain the requirements listed in Table X-1021. The written procedure shall establish a single value, or range of values, for each requirement.

X-1021.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement in Table X-1021 identified as an *essential* variable, from the specified value, or range of values, shall require requalification of the written procedure. A change of a requirement identified as a *nonessential* variable from the specified value, or range of values, does not require requalification of the written procedure. All changes of the essential and nonessential elements from the value, or range of values, specified by the written procedure shall require revision of, or an addendum to, the written procedure.

X-1030 EQUIPMENT

X-1031 Instrument

An electronic ultrasonic leak detector capable of detecting acoustic energy in the range of 20 to 100

TABLE X-1021
REQUIREMENTS OF AN ULTRASONIC LEAK TESTING
PROCEDURE

Requirement	Essential Variable	Non- Essential Variable
Instrument Manufacturer & Model	X	
Leak standard (decrease in size only)	X	
Pressurizing gas	X	
Test pressure (decrease in pressure only)	X	
Soak time (decrease in time only)	X	
Scanning distance (increase in distance only)	X	
Scanning rate (increase in rate only)	X	
Signaling device		X
Personnel Qualification		X

kHz shall be utilized. Leakage shall be indicated by one or more of the following signaling devices:

(a) *Meter* — A meter on the test instrument, or a probe, or both.

(b) *Audio Device* — A set of headphones that emit(s) audible indications.

X-1032 Capillary Calibration Leak Standard

A capillary type leak standard per Article 10, T-1063.2.

X-1060 CALIBRATION

X-1061 Standard Leak Size

The maximum leakage rate Q for the leak standard in X-1032 shall be 1×10^{-1} std cm³/s (1×10^{-2} Pa m³/s), unless otherwise specified by the referencing Code Section.

X-1062 Warm-up

The detector shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibration.

X-1063 Scanning Rate

The leak standard shall be attached to a pressure regulated gas supply and the pressure set to that to be used for the test. The detector shall be calibrated by directing the detector/probe towards the leak standard at the maximum scanning distance to be utilized during testing and noting the meter deflection and/or pitch of the audible signal as the detector/probe is scanned across the leak standard. The scanning rate shall not exceed that which can detect leakage rate Q from the leak standard.

X-1064 Frequency and Sensitivity

Unless otherwise specified by the referencing Code Section, the sensitivity of the detector shall be verified before and after testing, and at intervals of not more than 4 hr during testing. During any verification check, should the meter deflection or audible signal indicate that the detector/probe cannot detect leakage per X-1063, the instrument shall be recalibrated and areas tested after the last satisfactory calibration check shall be retested.

X-1070 TEST**X-1071 Location of Test**

The component to be tested shall, if possible, be removed or isolated from other equipment or structures that could generate ambient or system noise that can drown out leaks.

X-1072 Soak Time

Prior to testing, the test pressure shall be held a minimum of 15 min.

X-1073 Scanning Distance

After the required soak time per X-1072, the detector shall be passed over the test surface. The scanning distance shall not exceed that utilized to determine the maximum scanning rate in X-1063.

X-1074 Scanning Rate

The maximum scanning rate shall be as determined in X-1063.

X-1075 Leakage Detection

Leakage shall be indicated and detected according to X-1031.

X-1080 EVALUATION**X-1081 Leakage**

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the allowable rate of 1×10^{-1} std cm³/s (1×10^{-2} Pa m³/s).

X-1082 Repair/Retest

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

X-1090 DOCUMENTATION**X-1091 Examination Report**

The report of examination shall contain the following information:

- (a) procedure ID and revision;
- (b) manufacturer and model number of instrument;
- (c) calibration leak standard size and serial number;
- (d) pressurizing gas and test pressure;
- (e) soak time;
- (f) maximum scanning distance and rate;
- (g) map or record of rejectable leakage or areas cleared;
- (h) identification of welds or areas scanned;
- (i) examination personnel identity;
- (j) date of examination.

X-1092 Performance Demonstration Report

Performance demonstrations, when required by the referencing Code Section, shall be documented.

ARTICLE 10

NONMANDATORY APPENDIX

APPENDIX A — SUPPLEMENTARY LEAK TESTING FORMULA SYMBOLS

01 A-10 APPLICABILITY OF THE FORMULAS

(a) The formulas in this Article provide for the calculated leak rate(s) for the technique used.

(b) The symbols defined below are used in the formulas of the appropriate Appendix.

(1) System sensitivity calculation:

S_1 =preliminary sensitivity (calculation of sensitivity), std $\text{cm}^3/\text{s}/\text{div}$ ($\text{Pa m}^3/\text{s}/\text{div}$)

S_2 =final sensitivity (calculation of sensitivity), std $\text{cm}^3/\text{s}/\text{div}$ ($\text{Pa m}^3/\text{s}/\text{div}$)

(2) System measured leakage rate calculation:

Q =measured leakage rate of the system (corrected for tracer gas concentration), std cm^3/s ($\text{Pa m}^3/\text{s}$)

(3) System Correction Factors:

$PSCF$ =Preliminary System Correction Factor

$FSCF$ =Final System Correction Factor

(4) Tracer gas concentration:

$\%TG$ = concentration of Tracer Gas, %

(5) Calibrated standard:

CL =calibrated leak leakage rate, std cm^3/s ($\text{Pa m}^3/\text{s}$)

(6) Instrument reading sequence:

M_1 =meter reading before test with calibrated leak open to the component [divisions, or std cm^3/s ($\text{Pa m}^3/\text{s}$)]

M_2 =meter reading before test with calibrated leak closed to component [divisions, or std cm^3/s ($\text{Pa m}^3/\text{s}$)] (system background noise reading)

M_3 =meter reading (registering component leakage) with calibrated leak closed [divisions, or std cm^3/s ($\text{Pa m}^3/\text{s}$)]

M_4 =meter reading (registering component leakage) with calibrated leak open [divisions, or std cm^3/s ($\text{Pa m}^3/\text{s}$)]

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ARTICLE 11

ACOUSTIC EMISSION EXAMINATION OF FIBER-REINFORCED PLASTIC VESSELS

T-1110 SCOPE

(a) This Article describes or references requirements which are to be used in applying acoustic emission (AE) examination of new and inservice fiber reinforced plastic (FRP) vessels under pressure, vacuum, or other applied stress.

(b) Test pressure used during examination shall not exceed 1.5 times the maximum allowable working pressure (MAWP). Vacuum testing can be full design vacuum. These values are subordinate to stress values in specific procedures outlined in Section X, Part T, Rules Covering Testing, of the ASME Boiler and Pressure Vessel Code.

(c) This Article is limited to vessels with glass or other reinforcing material contents greater than 15% by weight.

T-1120 GENERAL

(a) When this Article is specified by a referencing Code Section, the method described in this Article shall be used together with Article 1, General Requirements. Definitions of terms used in this Article are found in Mandatory Appendix III of this Article.

(b) Discontinuities located with AE shall be evaluated by other methods, e.g., visual, ultrasonic, liquid penetrant, etc., and shall be repaired and retested as appropriate.

T-1121 Vessel Conditioning

For tanks and pressure vessels that have been stressed previously, the operating pressure and/or load shall be reduced prior to testing according to the schedule shown in Table T-1121. In order to properly evaluate the AE examination, the maximum operating pressure or load on the vessel during the past year must be known, and recorded.

TABLE T-1121
REQUIREMENTS FOR REDUCED OPERATING LEVEL
IMMEDIATELY PRIOR TO EXAMINATION

Percent of Operating Maximum Pressure and/or Load	Time Spent at Percent of Maximum Pressure and/or Load
10 or less	12 hr
20	18 hr
30	30 hr
40	2 days
50	4 days
60	7 days

EXAMPLE:

For an inservice vessel, two factors must be known prior to making a test:

- (1) The maximum operating pressure or load during the past year
- (2) The test pressure

Table T-1121 is used as follows. The reduced pressure is divided by the maximum operating pressure and the quantity is expressed as a percent. This value is entered in the first column and the corresponding row in the second column shows the time required at the reduced pressure, prior to making an AE test. When the ratios fall between two values in the second column the higher value is used.

T-1122 Vessel Stressing

Arrangements shall be made to stress the vessel to the design pressure and/or load. The rate of application of stress and load shall be sufficient to expedite the examination with the minimum extraneous noise. Holding stress levels is a key aspect of an acoustic emission examination. Accordingly, provision must be made for holding the pressure and/or load at designated checkpoints.

(a) *Atmospheric Vessels.* Process liquid is the preferred fill medium for atmospheric vessels. If water must replace the process liquid, the designer and user

shall be in agreement on the procedure to achieve acceptable stress levels.

(b) *Vacuum Vessel Stressing.* A controllable vacuum pump system is required for vacuum tanks.

T-1123 Vessel Support

All vessels shall be examined in their operating position and supported in a manner consistent with good engineering practice. Flat bottomed vessels examined in other than the intended location shall be mounted on a noise-isolating pad on a concrete base or equivalent during the examination.

T-1124 Environmental Conditions

The minimum acceptable vessel wall temperature is 40°F (4°C) during the examination. Evaluation criteria are based above 40°F (4°C). For vessels designed to operate above 120°F (49°C), the test fluid shall be within ±10°F (5.6°C) of the design operating temperature. [At the option of the owner, the vessel test pressure may be increased to compensate for testing at elevated temperatures (120°F) (49°C).] Sufficient time shall be allowed before the start of the test for the temperature of the vessel shell and the test fluid to reach equilibrium.

T-1125 Noise Elimination

Noise sources in the test frequency and amplitude range, such as rain, spargers, and foreign objects contacting the vessels, must be minimized since they mask the AE signals emanating from the structure. The filling inlet should be at the lowest nozzle or as near to the bottom of the vessel as possible, i.e., below the liquid level.

T-1126 Instrumentation Settings

Settings shall be determined as described in Appendix II of this Article.

T-1127 Sensors

(a) *Sensor Mounting.* The location and spacing of the sensor are in T-1141(c). The sensors shall be placed in the designated locations with the couplant specified in the testing procedure between the sensor and test article. Assure that adequate couplant is applied. The

sensor shall be held in place utilizing methods of attachment which do not create extraneous signals, as specified in the test procedure. Suitable adhesive systems are those whose bonding and acoustic coupling effectiveness have been demonstrated. The attachment method shall provide support for the signal cable (and preamplifier) to prevent the cable(s) from stressing the sensor or causing loss of coupling.

(b) *Surface Contact.* Sensors shall be mounted directly on the vessel surface, or integral waveguides shall be used. (Possible signal losses may be caused by coatings such as paint and encapsulants, as well as by construction surface curvature and surface roughness at the contact area.)

(c) *High and Low Frequency Channels.* An AE instrument channel is defined as a specific combination of sensor, preamplifier, filter, amplifier, and cable(s). Both high and low frequency channels shall be used. High frequency channels shall be used for detection and evaluation of AE sources. Low frequency channels shall be used to evaluate the coverage by high frequency sensors.

(d) *High Frequency Sensors.* (See Appendix I-1111.) Several high frequency channels shall be used for zone location of emission sources. This is due to greater attenuation at higher frequencies.

(e) *Low Frequency Sensors.* (See Appendix I-1112.) At least two low frequency channels shall be used. If significant activity is detected on the low frequency channels and not on high frequency channels, high frequency sensor location shall be evaluated by the examiner.

T-1128 Procedure Requirements

01

Acoustic emission examination shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable:

- (a) material and configurations to be examined including dimensions and product form;
- (b) method for determination of sensor locations;
- (c) sensor locations;
- (d) couplant;
- (e) method of sensor attachment;
- (f) sensor type, frequency, and locations;
- (g) acoustic emission instrument type and frequency;
- (h) description of system calibration;
- (i) data to be recorded and method of recording;
- (j) report requirements;
- (k) post-examination cleaning;
- (l) qualification of the examiner(s).

T-1130 EQUIPMENT AND SUPPLIES

(a) The AE system consists of sensors, signal processing, display, and recording equipment. (See Appendix I.)

(b) The system shall be capable of recording AE counts and AE events above a threshold within a frequency range of 25 kHz–300 kHz and have sufficient channels to localize AE sources. It may incorporate (as an option) peak amplitude detection.

NOTE: Event detection is required for each channel.

Amplitude distributions are recommended for flaw characterization. The AE system is further described in Appendix I.

(c) Capability for measuring time and pressure shall be provided and recorded. The pressure and/or vacuum (in the vessel) shall be continuously monitored to an accuracy of $\pm 2\%$ of the maximum test pressure.

T-1140 APPLICATION REQUIREMENTS**T-1141 Vessels**

(a) *Equipment.* (See T-1130 and Mandatory Appendix I.)

(b) *System Calibration.* (See Mandatory Appendix II.)

(1) *Attenuation Characterization.* Typical signal propagation losses shall be determined according to one of the following techniques. These techniques provide a relative measure of the attenuation. The peak amplitude from a pencil break may vary with surface hardness, resin condition, fiber orientation, and cure.

(2) For acoustic emission instrumentation with amplitude analysis:

Select a representative region of the vessel away from manways, nozzles, etc. Mount a high frequency AE sensor and locate points at distances of 6 in. (152 mm) and 12 in. (305 mm) from the center of the sensor along a line parallel to one of the principal directions of the surface fiber (if applicable). Select two additional points at 6 in. (152 mm) and 12 in. (305 mm) along a line inclined 45 deg. to the direction of the original points. At each of the four points, break 0.3 mm 2H pencil leads and record peak amplitude. A break shall be done at an angle of approximately 30 deg. to the test surface with a 0.1 in. (2.5 mm) lead extension. This amplitude data from successive lead breaks shall be part of the report.

(3) For systems without amplitude analysis:

Select a representative region of the vessel away from manways, nozzles, etc. Mount a high frequency AE sensor and break 0.3 mm pencil leads along

a line parallel to one of the principal directions of the surface fibers.

Record the distances from the center of the sensor at which the recorded amplitude equals the reference amplitude and the threshold of acoustic emission detectability (see Appendix II). Repeat this procedure along a line inclined 45 deg. to the direction of the original line. This distance data shall be part of the report.

(c) *Sensor Locations and Spacings.* Locations on the vessel shell are determined by the need to detect structural flaws at critical sections, e.g., high stress areas, geometric discontinuities, nozzles, manways, repaired regions, support rings, and visible flaws. High frequency sensor spacings are governed by the attenuation of the FRP material. Sensor location guidelines for typical tank types are given in Nonmandatory Appendix A.

(1) *Sensor Spacing.* The recommended high frequency sensor spacing on the vessel shall be not greater than three times the distance at which the recorded amplitude from the attenuation characterization equals the threshold of detectability (see Appendix II). Low frequency sensors shall be placed in areas of low stress and at a maximum distance from one another.

(d) *Systems Performance Check*

(1) *Sensor Coupling and Circuit Continuity Verification.* Verification shall be performed following sensor mounting and system hookup and immediately following the test. A record of the verifications shall be recorded in the report.

(2) *Peak Amplitude Response.* The peak amplitude response of each sensor-preamplifier combination to a repeatable simulated acoustic emission source shall be taken and recorded following sensor mounting. The peak amplitude of the simulated event at a specific distance greater than 3 in. (76 mm) from each sensor shall not vary more than 6 dB from the average of all the sensors.

(3) Post-test verification using the procedure in (d)(2) above shall be done and recorded for the final report.

T-1142 Examination Procedure

(a) *General Guidelines.* The vessel is subjected to programmed increasing stress levels to a predetermined maximum while being monitored by sensors that detect acoustic emission caused by growing structural discontinuities.

Rates of filling and pressurization shall be controlled so as not to exceed the strain rate specified by the referencing Code Section.

The desired pressure will be attained with a liquid. Pressurization with a gas (air, N₂, etc.) is not permitted. A suitable manometer or other type gage shall be used to monitor pressure. Vacuum shall be attained with a suitable vacuum source.

A quick-release valve shall be provided to handle any potential catastrophic failure condition.

(b) *Background Noise.* Background noise should be identified, minimized, and recorded.

(1) *Background Noise of Check Prior to Loading.* AE monitoring of the vessel is required to identify and determine the level of spurious signals following the completion of the system performance check and prior to stressing the vessel. A recommended monitoring period is 10 min to 30 min. If background noise is excessive, the source of the noise shall be eliminated or the examination terminated.

(2) *Background Noise During Examination.* In the AE examiner's analysis of examination results, background noise shall be noted and its effects on test results evaluated. Sources of background noise include liquid splashing into a vessel; a fill rate that is too high; pumps, motors, agitators, and other mechanical devices; electromagnetic interference; and environment (rain, wind, etc.).

(c) *Stressing*

(1) *Atmospheric Vessel Loading.* Stressing sequences for new atmospheric vessels and vacuum vessels are shown in Figs. T-1142(c)(1)(a) and (b). The test algorithm-flowchart for this class of vessels is given in Fig. T-1142(c)(1)(c).

(2) *Pressure Vessel Stressing.* Pressure vessels which operate with superimposed pressures greater than 14.7 psi above atmospheric shall be stressed as shown in Fig. T-1142(c)(2)(a). The test algorithm flowchart for this class of tanks is given in Fig. T-1142(c)(2)(b).

(3) For all vessels, the final stress hold shall be for 30 min. The vessel should be monitored continuously during this period.

(d) *AE Activity.* If significant [see T-1183(b)] AE activity is detected during the test on low frequency channels, and not on high frequency channels, the examiner may relocate the high frequency channels.

(e) *Test Termination.* Departure from a linear count/load relationship shall signal caution. If the AE count rate increases rapidly with load, the vessel shall be unloaded and the test terminated. [A rapidly (exponentially) increasing count rate indicates uncontrolled continuing damage and is indicative of impending failure.]

T-1160 CALIBRATION (See Mandatory Appendix II)

T-1180 EVALUATION

T-1181 Evaluation Criteria

The acoustic emission criteria shown in Table T-1181 are set forth as a basis for assessing the severity of structural flaws in FRP vessels. These criteria are based only on high frequency sensors. Low frequency sensors are used to monitor the entire vessel.

T-1182 Emissions During Load Hold E_H

The criterion based on emissions during load hold is particularly significant. Continuing emissions indicate continuing damage. Fill and other background noise will generally be at a minimum during a load hold.

T-1183 Felicity Ratio Determination

The felicity ratio is obtained directly from the ratio of the load at onset of emission and the maximum prior load. The felicity ratio is not measured during the first loading of pressure, atmospheric, or vacuum vessels.

(a) During the first loading of FRP vessels, the felicity ratio is measured from the unload/reload cycles. For subsequent loadings, the felicity ratio is obtained directly from the ratio of the load at onset of emission and the previous maximum load. A secondary felicity ratio is determined from the unload/reload cycles.

(b) The criterion based on felicity ratio is important for inservice vessels. The criterion provides a measure of the severity of previously induced damage. The onset of "significant" emission is used for determining measurement of the felicity ratio, as follows:

(1) more than 5 bursts of emission during a 10% increase in stress;

(2) more than $N_c/25$ counts during a 10% increase in stress, where N_c is the count criterion defined in Appendix II-1140;

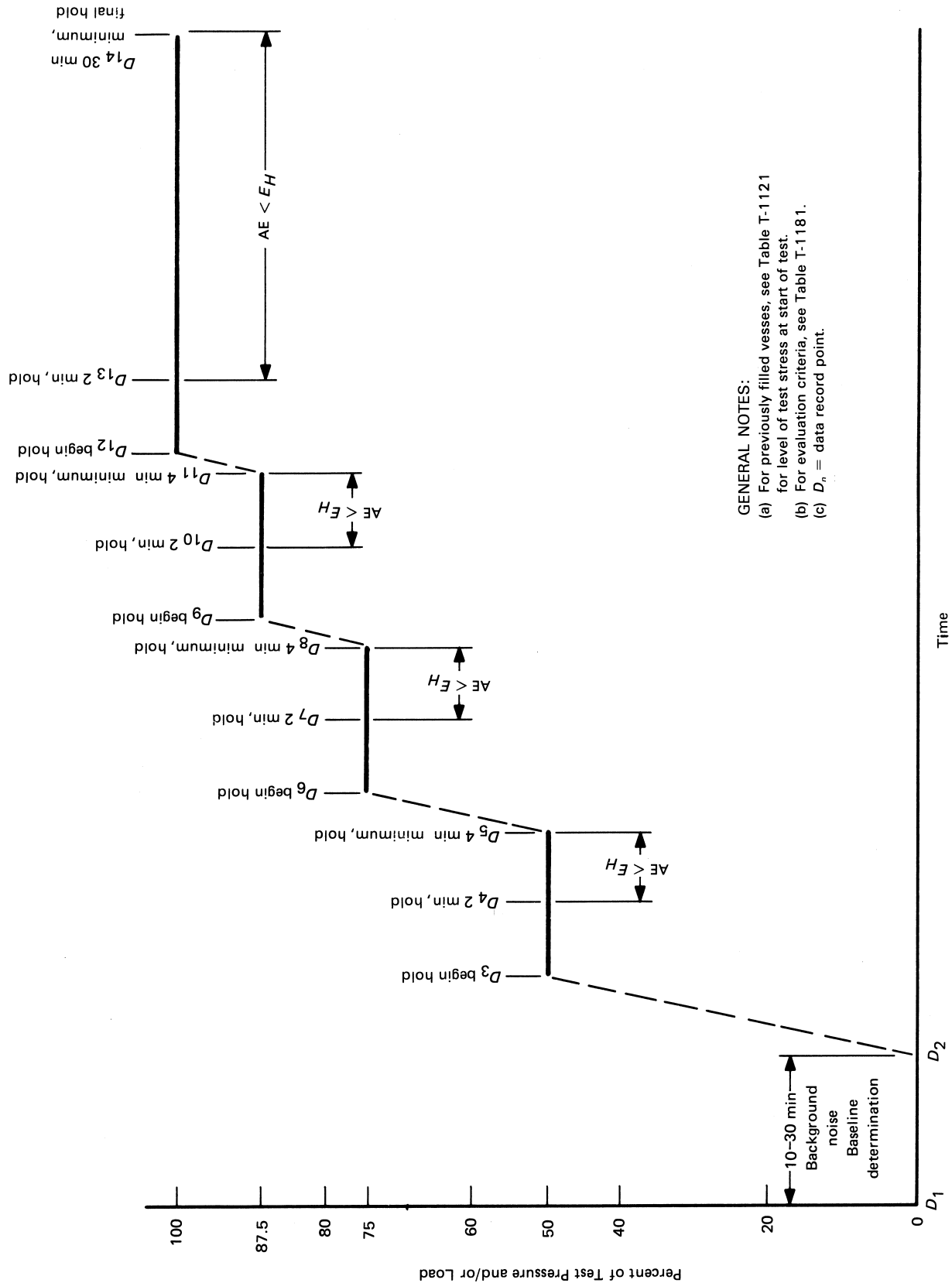
(3) emission continues at a stress hold. For the purpose of this guideline, a short (1 min or less) nonprogrammed load hold can be inserted in the procedure.

T-1184 High Amplitude Events Criterion

The high amplitude events criterion is often associated with fiber breakage and is indicative of major structural

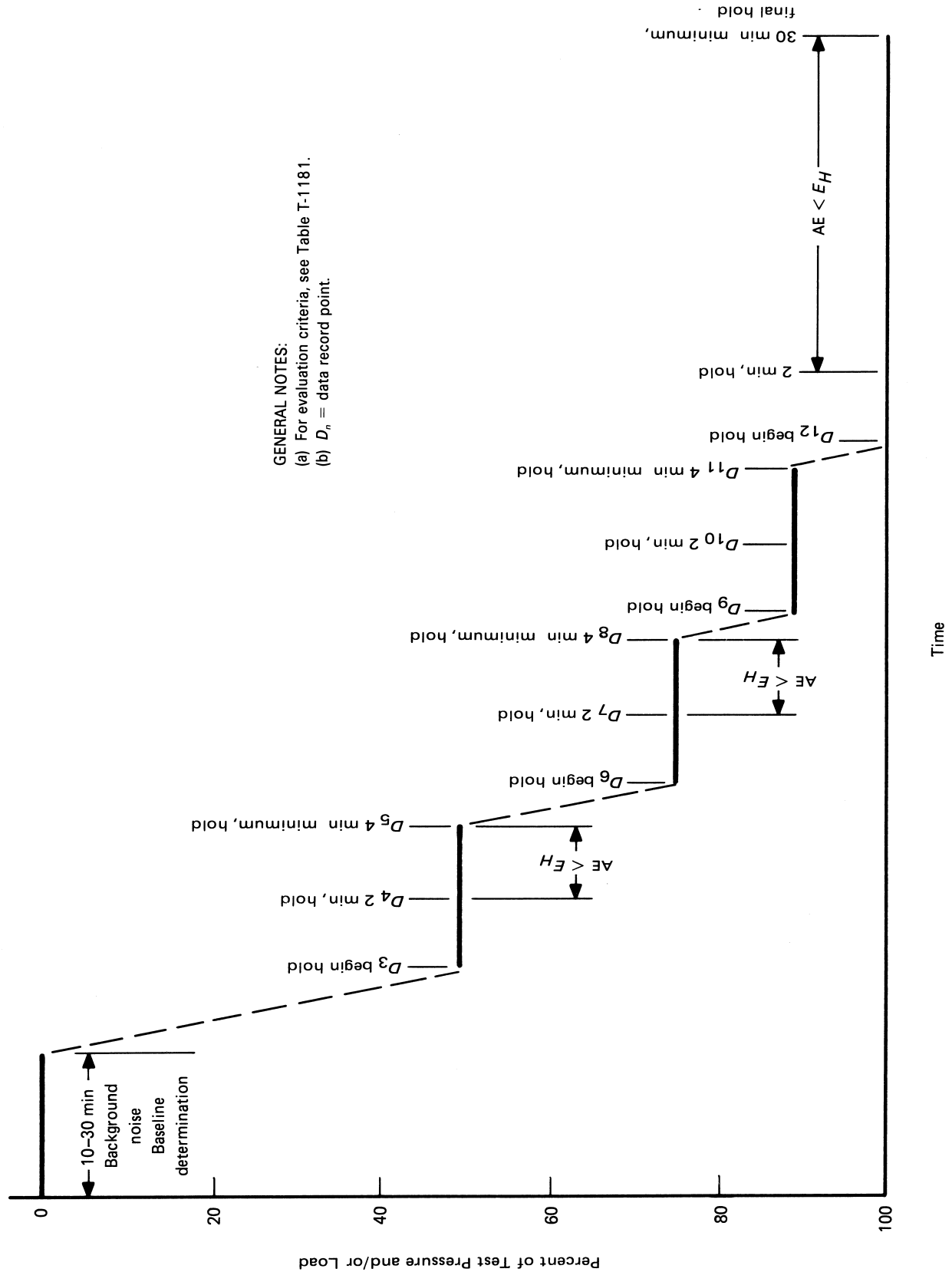
Fig. T-1142(c)(1)(a)

2001 SECTION V



GENERAL NOTES:
(a) For previously filled vessels, see Table T-1121 for level of test stress at start of test.
(b) For evaluation criteria, see Table T-1181.
(c) D_n = data record point.

FIG. T-1142(c)(1)(a) ATMOSPHERIC VESSELS STRESSING SEQUENCE



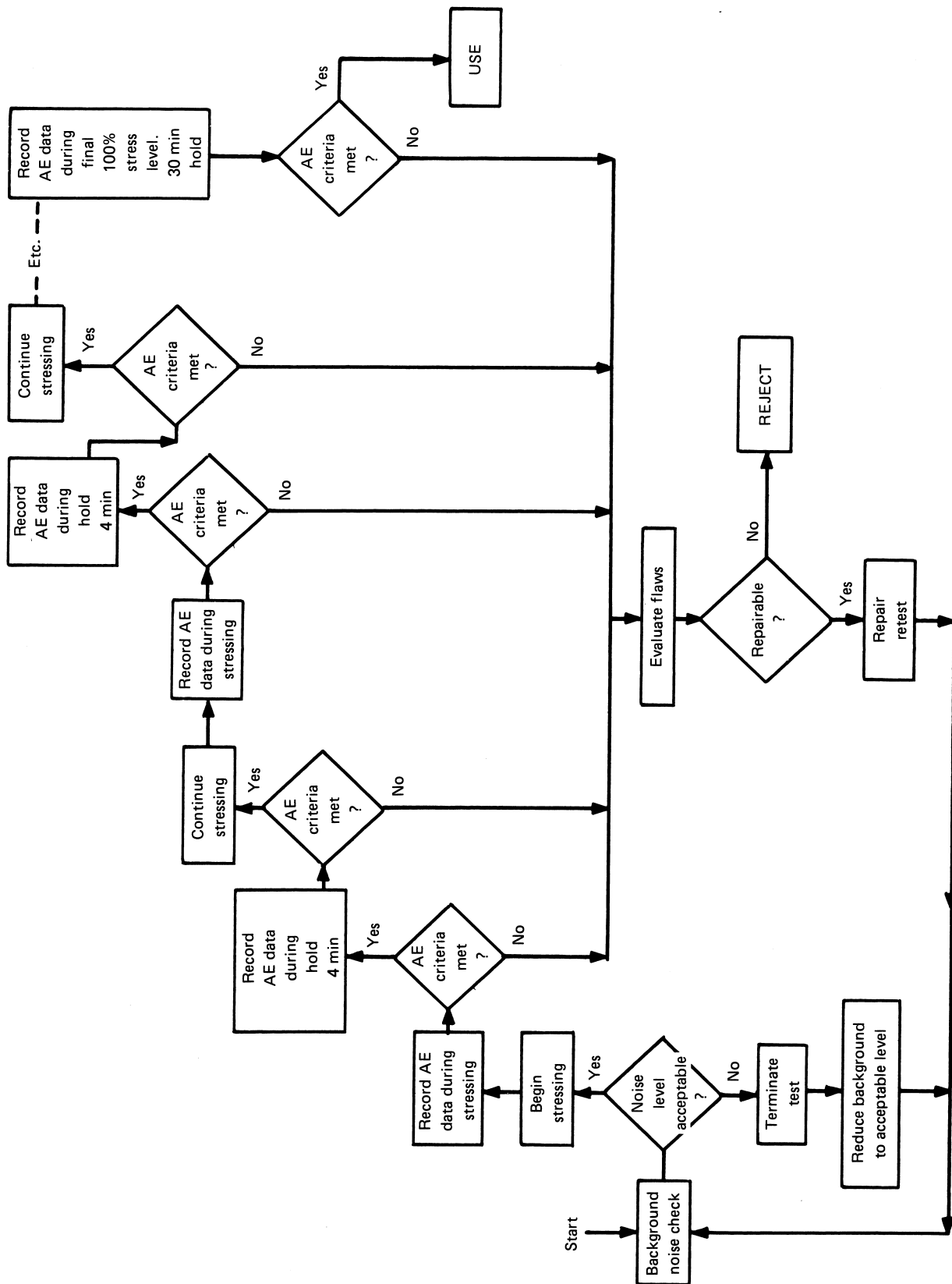


FIG. T-1142(c)(1)(c) TEST ALGORITHM — FLOWCHART FOR ATMOSPHERIC VESSELS

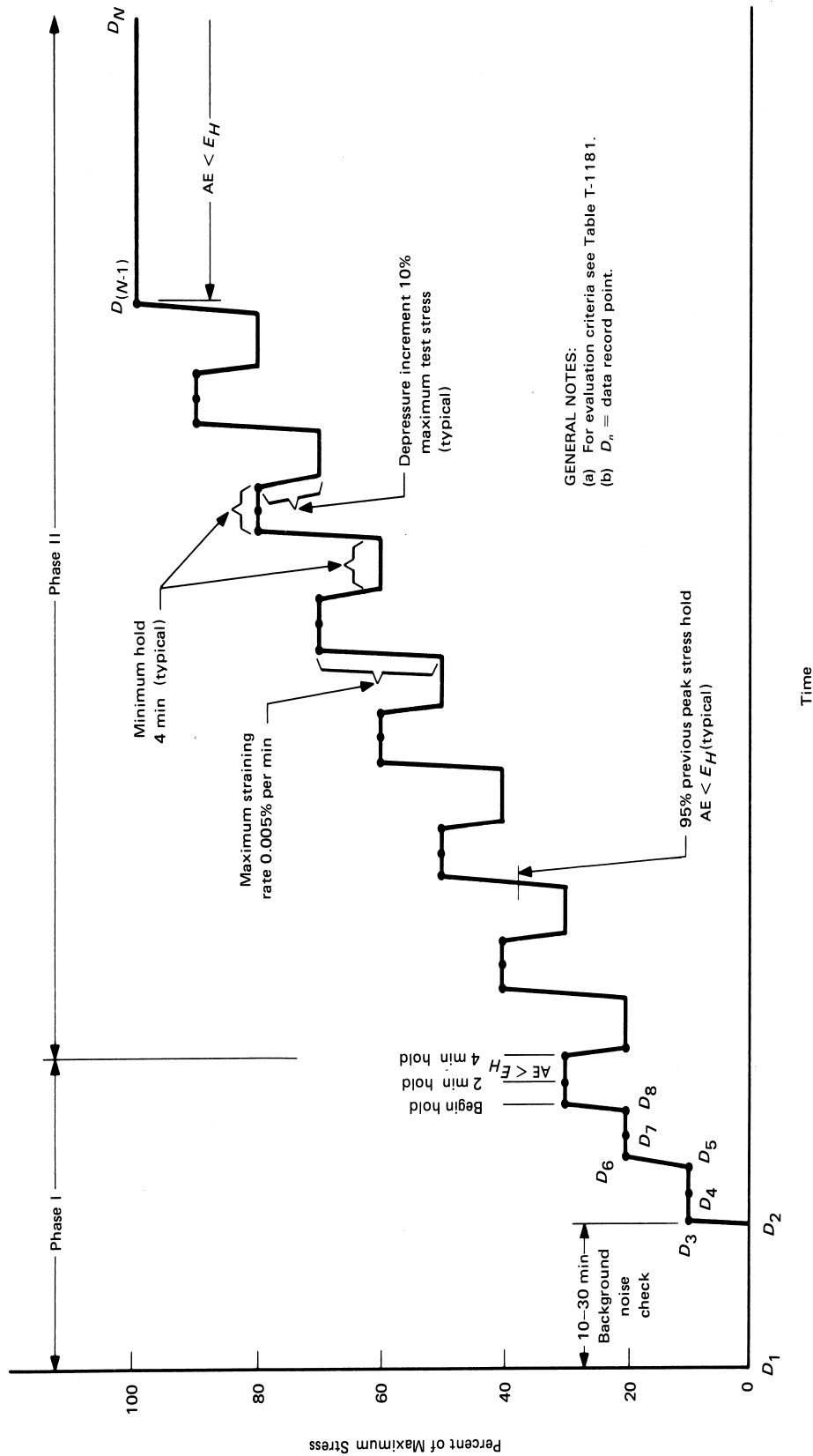


FIG. T-1142(c)(2)(a) PRESSURE VESSEL STRESSING SEQUENCE

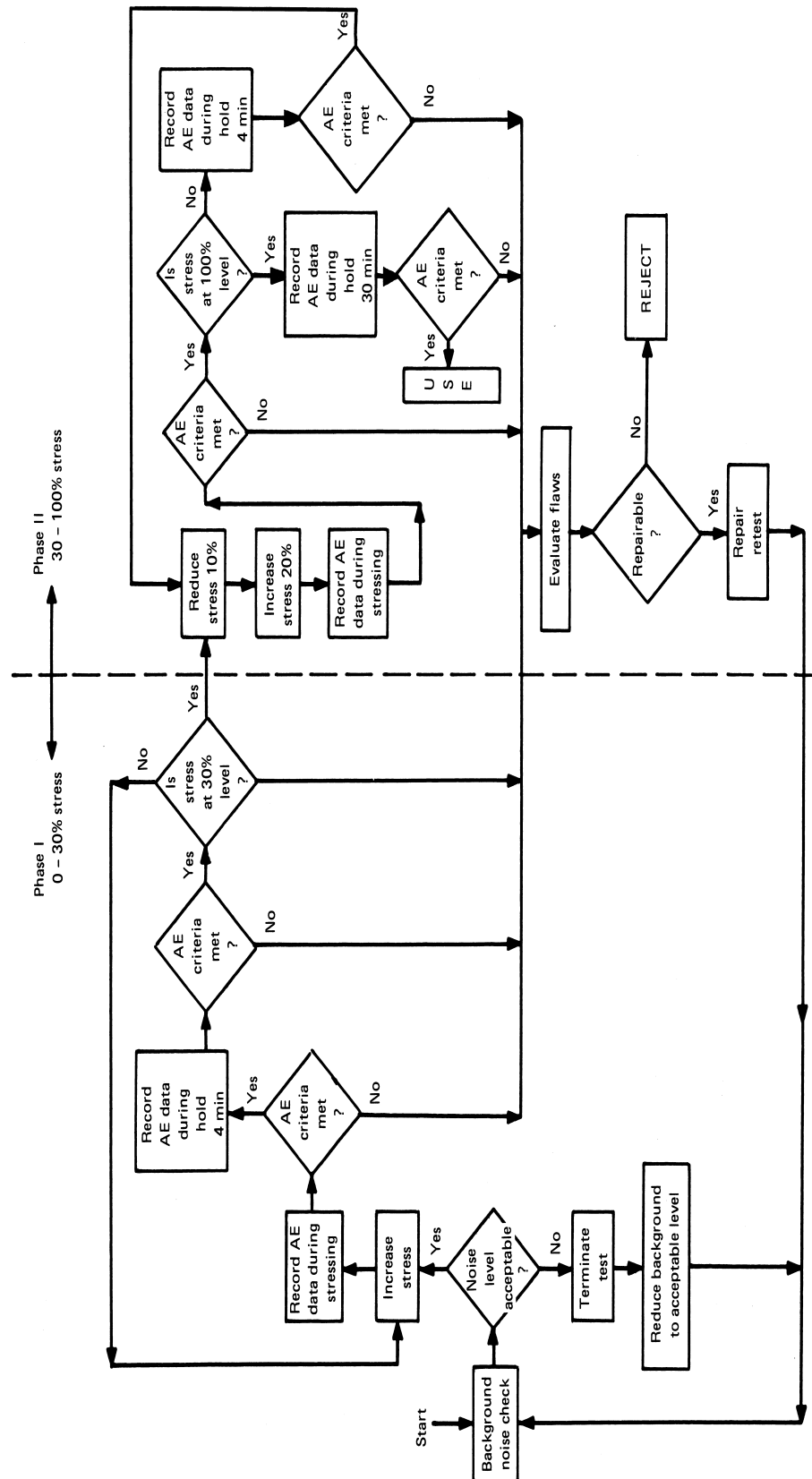


TABLE T-1181
EVALUATION CRITERIA
Atmospheric (Liquid Head) and Additional¹ Superimposed Pressure

	First Loading	Subsequent Loading	
Emissions during hold	Less than E_H events beyond time T_H , none having an amplitude greater than A_M [Note (2)]	Less than E_H events beyond time T_H	Measure of continuing permanent damage [Note (3)]
Felicity ratio	Greater than felicity ratio F_A	Greater than felicity ratio F_A	Measure of severity of previous induced damage
Total [Note (4)]	Not excessive [Note (5)]	Less than N_c total counts	Measure of overall damage during a load cycle
M [Note (6)]	No events with a duration greater than M	No events with a duration greater than M	Measure of delamination, adhesive bond failure, and major crack growth
Number of events greater than reference amplitude threshold	Less than E_A events	Less than E_A events	Measure of high energy microstructure failures. This criterion is often associated with fiber breakage.

GENERAL NOTE: A_M , E_A , E_H , F_A , N_c , and M are acceptance criteria values specified by the referencing Code Section; T_H is specified hold time.

NOTES:

- (1) Above atmospheric
- (2) See Appendix II-1140 for definition of A_M .
- (3) Permanent damage can include microcracking, debonding, and fiber pull out.
- (4) Varies with instrumentation manufacturer; see Appendix II for functional definition of N_c . Note that counts criterion N_c may be different for first and subsequent fillings.
- (5) Excessive counts are defined as a significant increase in the rate of emissions as a function of load. On a plot of counts against load, excessive counts will show as a departure from linearity.
- (6) If used, varies with instrumentation manufacturer; see Appendix II-1150 for functional definition.

damage in new vessels. For inservice and previously stressed vessels, emissions during a stress hold and felicity ratio are important.

T-1185 Total Counts Criterion

The criteria based on total counts are valuable for pressure or atmospheric and vacuum vessels. Pressure vessels, particularly during first stressing, tend to be noisy.

Excessive counts, as defined in Table T-1181, are important for all vessels, and are a warning of impending failure.

T-1190 DOCUMENTATION

T-1191 Report

The report shall include the following:

- (a) complete identification of the vessel, including

material type, source, method of fabrication, Manufacturer's name and code number, and previous history of maintenance, as well as relaxation operation data from Table T-1121, prior to testing;

(b) vessel sketch or Manufacturer's drawing with dimensions and sensor locations;

(c) test liquid employed;

(d) test liquid temperature;

(e) test sequence — load rate, hold times, and hold levels;

(f) correlation of test data with the acceptance criteria;

(g) a sketch or Manufacturer's drawings showing the location of any zone not meeting the evaluation criteria;

(h) any unusual effects or observations during or prior to the test;

(i) date(s) of test;

(j) name(s) and qualifications of the test operator(s);

(k) complete description of AE instrumentation including Manufacturer's name, model number, sensor type, system gain, etc.

T-1192 Record

- (a) A permanent record of AE data includes:
- (1) AE events above threshold vs time for zones of interest;
 - (2) total counts vs time, etc.;
 - (3) signal propagation loss.
- (b) The AE data shall be maintained with the records of the vessel.

ARTICLE 11

MANDATORY APPENDICES

APPENDIX I — INSTRUMENTATION PERFORMANCE REQUIREMENTS

I-1110 AE SENSORS

AE sensors shall be temperature stable over the range of use which may be 40°F–200°F (4°C–93°C), and shall not exhibit sensitivity changes greater than 3 dB over this range. Sensors shall be shielded against radio frequency and electromagnetic noise interference through proper shielding practice and/or differential (anticoincident) element design. Sensors shall have a frequency response with variations not exceeding 4 dB from the peak response.

I-1111 High Frequency Sensors

These sensors shall have a resonant response at 100 kHz–200 kHz. Minimum sensitivity shall be –80 dB referred to 1 volt/microbar, determined by face-to-face ultrasonic calibration. AE sensors used in the same test should not vary in peak sensitivity more than 3 dB from the average.

I-1112 Low Frequency Sensors

These sensors shall have a resonant response between 25 kHz and 75 kHz. Minimum sensitivity shall be comparable to, or greater than, commercially available high sensitivity accelerometers with resonant response in that frequency range. In service, these sensors may be wrapped or covered with a sound-absorbing medium to limit interference by airborne noise, if permitted in the procedure used in making the examination.

I-1120 SIGNAL CABLE

The signal cable from sensor to preamp shall not exceed 6 ft (1.8 m) in length and shall be shielded against electromagnetic interference. This requirement is omitted where the preamplifier is mounted in the

sensor housing, or a line-driving (matched impedance) sensor is used.

I-1130 COUPLANT

Commercially available couplants for ultrasonic flaw detection accumulated above second threshold may be used (high setting adhesives may also be used, provided couplant sensitivity is not significantly lower than with fluid couplants). Couplant selection should be made to minimize changes in coupling sensitivity during a test. Consideration should be given to testing time and the surface temperature of the vessel. The couplant and method of attachment are specified in the written procedure.

I-1140 PREAMPLIFIER

The preamplifier, when used, shall be mounted in the vicinity of the sensor, or may be in the sensor housing. If the preamp is of differential design, a minimum of 40 dB of common-mode noise rejection shall be provided. Unfiltered frequency response shall not vary more than 3 dB over the frequency range of 25 kHz–300 kHz, and over the temperature range of 40°F–125°F (4°C–52°C). For sensors with integral preamps, frequency response characteristics shall be confined to a range consistent with the operational frequency of the sensor.

I-1150 FILTERS

Filters shall be of the band pass or high pass type, and shall provide a minimum of –24 dB/octave signal attenuation. Filters may be located in preamplifier or post-preamplifier circuits, or may be integrated into the component design of the sensor, preamp, or processor to limit frequency response. Filters and/or integral design characteristics shall insure that the principal processing frequency for high frequency sensors is not

less than 100 kHz, and for low frequency sensors not less than 25 kHz.

I-1160 POWER-SIGNAL CABLE

The cable providing power to the preamplifier and conducting the amplified signal to the main processor shall be shielded against electromagnetic noise. Signal loss shall be less than 1 dB per 100 ft (30.5 m) of cable length. The recommended maximum cable length is 500 ft (152 m) to avoid excessive signal attenuation. Digital or radio transmission of signals is allowed if consistent with standard practice in transmitting those signal forms.

I-1161 Power Supply

A stable grounded electrical power supply, meeting the specifications of the instrumentation, shall be used.

I-1170 MAIN AMPLIFIER

The main amplifier, if used, shall have signal response with variations not exceeding 3 dB over the frequency range of 25 kHz–300 kHz, and temperature range of 40°F–125°F (4°C–52°C). The written procedure shall specify the use and nomenclature of the main amplifier.

The main amplifier shall have adjustable gain, or an adjustable threshold for event detection and counting.

I-1180 MAIN PROCESSOR

I-1181 General

The main processor(s) shall have a minimum of two active data processing circuits through which high frequency and low frequency sensor data will be processed independently. If independent channels are used, the processor shall be capable of processing events and counts on each channel. No more than two sensors may be commoned into a single preamplifier.

If a summer or mixer is used, it shall provide a minimum processing capability for event detection on eight channels (preamp inputs).

Low frequency sensor information will be processed for emission activity. Total counts will be processed from the high frequency sensors only. Events accumulated above second threshold (high amplitude events) will be processed from the high frequency sensors only. The high amplitude signal threshold may be established through signal gain reduction, threshold increase, or peak amplitude detection.

(a) *Threshold.* The AE instrument used for examination shall have a threshold control accurate to within ± 2 dB over its useful range.

(b) *Counts.* The AE instrument used for examination shall detect counts over a set threshold within an accuracy of $\pm 5\%$.

(c) *Events.* The AE instrument used for examination shall be capable of continuously measuring 100 events ± 1 event/sec, over a set threshold.

(d) *Peak Amplitude.* When peak amplitude detection is used, the AE instrument used for examination shall measure the peak amplitude within an accuracy of ± 2 dB over a set threshold.

(e) *M.* The AE instrument used for examination shall be capable of measuring an *M* value (if used).

(f) *Field Performance Verification.* At the beginning of each vessel test the performance of each channel of the AE instrument shall be checked using an electronic waveform generator and a stress wave generator.

(g) *Waveform Generator.* This device shall input a sinusoidal burst-type signal of measurable amplitude, duration, and carrier frequency. As a minimum, it shall be able to verify system operation for threshold, counts, and if used, duration, and peak amplitude measurements over the range of 25 kHz–200 kHz.

(h) *Stress Wave Generator.* This device shall transmit a stress wave pulse into the sensor. AE instrumentation response shall be within 5 dB of the response of the same sensor model when new.

The AE channel response to a single lead break shall be within 5 dB of the channel response of the same sensor model when new.

I-1182 Peak Amplitude Detection

If peak amplitude detection is practiced, comparative calibration must be established per the requirements of Appendix II. Usable dynamic range shall be a minimum of 60 dB with 5 dB resolution over the frequency band of 100 kHz–300 kHz, and the temperature range of 40°F–125°F (4°C–52°C). Not more than 2 dB variation in peak detection accuracy shall be allowed over the stated temperature range. Amplitude values may be stated in volts or dB, but must be referenced to a fixed gain output of the system (sensor or preamp).

I-1183 Signal Outputs and Recording

The processor as a minimum shall provide outputs for permanent recording of total counts for high frequency sensors, events by channel (zone location), and total events above the reference amplitude threshold for high

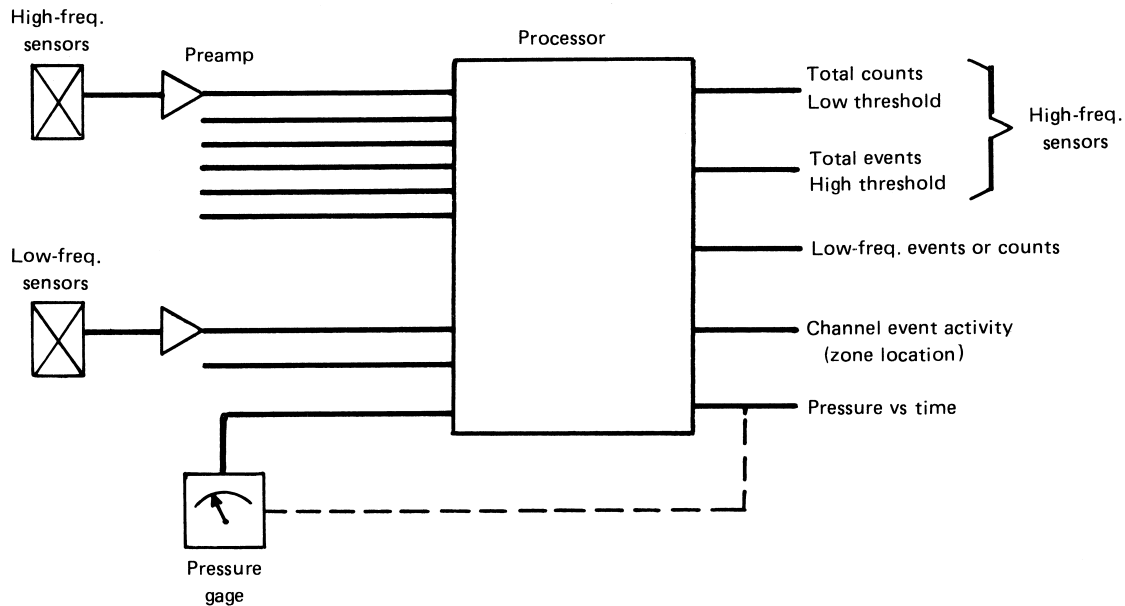


FIG. I-1183 SAMPLE OF SCHEMATIC OF AE INSTRUMENTATION FOR VESSEL EXAMINATION

frequency sensors. A sample schematic is shown in Fig. I-1183.

APPENDIX II — INSTRUMENT CALIBRATION

II-1110 GENERAL

The performance and threshold definitions vary for different types of acoustic emission equipment. Parameters such as counts, amplitude, energy, and M vary from manufacturer to manufacturer, and from model to model by the same manufacturer. This Appendix defines procedures for determining the threshold of acoustic emission detectability, reference amplitude threshold, and count criterion N_c .

The procedures defined in this Appendix are intended for baseline instrument calibration at 60°F to 80°F (16°C to 27°C). Instrumentation users shall develop calibration techniques traceable to the baseline calibration outlined in this Appendix. For field use, electronic calibrators, small portable samples (acrylic or similar), can be carried with the equipment and used for periodic checking of sensor, preamplifier, and channel sensitivity.

II-1120 THRESHOLD

Threshold of acoustic emission detectability shall be determined using a 4 ft × 6 ft × $\frac{1}{2}$ in. (1.2 m × 1.8 m × 13 mm) 99% pure lead sheet. The sheet shall be suspended clear of the floor. The threshold of detectability is defined as the average measured amplitude of ten events generated by 0.3 mm pencil (2H) lead break at a distance of 4 ft 3 in. (1.3 m) from the sensor. A break shall be done at an angle of approximately 30 deg. to the test surface with a 0.1 in. (2.5 mm) lead extension. The sensor shall be mounted 6 in. (152 mm) from the 4 ft (1.2 m) side and mid-distance between the 6 ft (1.8 m) sides.

II-1130 REFERENCE AMPLITUDE THRESHOLD

For large amplitude events, the reference amplitude threshold shall be determined using a 10 ft × 2 in. × $\frac{3}{4}$ in. (3.0 m × 51 mm × 19 mm) clean, mild steel bar. The bar shall be supported at each end by elastomeric, or similar, isolating pads. The reference amplitude threshold is defined as the average measured amplitude of ten events generated by a 0.3 mm pencil (2H) lead break at a distance of 7 ft (2.1 m) from the sensor (see Appendix II-1120). A break shall be done at an

angle of approximately 30 deg. to the test surface with a 0.1 in. (2.5 mm) lead extension. The sensor shall be mounted 12 in. (305 mm) from the end of the bar on the 2 in. (51 mm) wide surface.

II-1140 COUNT CRITERION N_c AND A_M VALUE

The count criterion N_c shall be determined either before or after the test using a 0.3 mm pencil (2H) lead broken on the surface of the vessel. A break shall be done at an angle of approximately 30 deg. to the test surface with a 0.1 in. (2.5 mm) lead extension. Calibration points shall be chosen so as to be representative of different constructions and thicknesses and should be performed above and below the liquid line (if applicable), and away from manways, nozzles, etc.

Two calibrations shall be carried out for each calibration point. One calibration shall be in the principal direction of the surface fibers (if applicable), and the second calibration shall be carried out along a line at 45 deg. to the direction of the first calibration. Breaks shall be at a distance from the calibration point so as to provide an amplitude decibel value A_M midway between the threshold of detectability (see Appendix II-1120) and reference amplitude threshold (see Appendix II-1130).

The count criterion N_c shall be based on the counts recorded from a defined (referencing Code Section) number of 0.3 mm pencil (2H) lead breaks at each of the two calibration points.

When applying the count criterion, the count criterion value, which is representative of the region where activity is observed, should be used.

II-1150 MEASUREMENT OF M

M is a measure of delamination, adhesive bond failure, or major crack growth. Different techniques

are used by different instrument manufacturers for measuring M . The units of the M value will vary depending upon the techniques and instrument that are used. Numerical values of M are normally defined from an electronically generated input signal. The value of M will be specified by the referencing Code Section.

II-1160 FIELD PERFORMANCE

As installed on the vessel, no channel shall deviate by more than 6 dB from the average peak response of all channels when lead breaks, or other simulated transient sources, are introduced 6 in. (152 mm) from the sensor.

APPENDIX III — GLOSSARY OF TERMS FOR ACOUSTIC EMISSION EXAMINATION OF FIBER-REINFORCED PLASTIC VESSELS

III-1110 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms related to examination of fiber-reinforced plastic vessels with acoustic emission.

III-1120 GENERAL REQUIREMENTS

(a) The standard terminology for Nondestructive Examinations, ASTM E 1316, has been adopted by the Committee as SE-1316.

(b) SE-1316 defines the terms that are used in conjunction with this Article.

(c) For general terms, such as *interpretation*, *flaw*, *discontinuity*, *evaluation*, etc., refer to Article 1, Mandatory Appendix I.

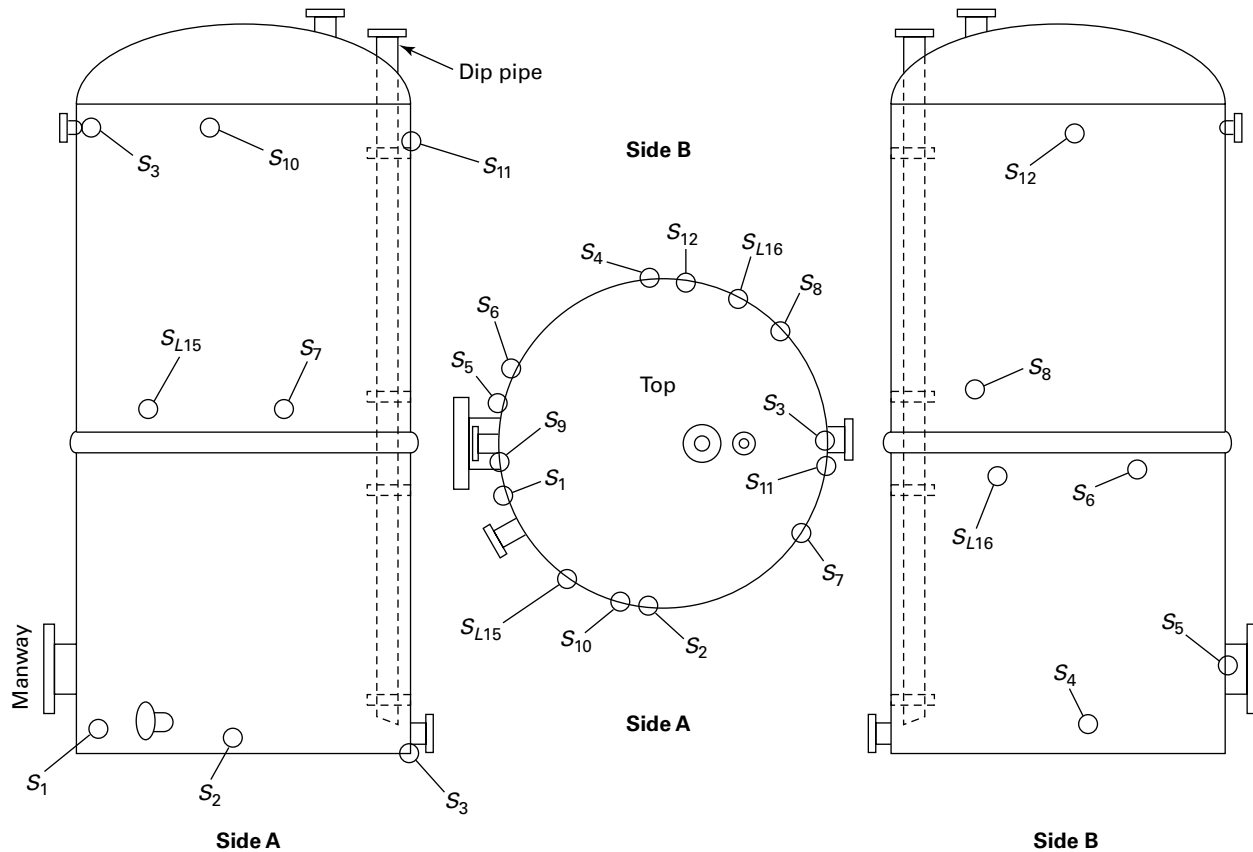
ARTICLE 11

NONMANDATORY APPENDIX

Appendix A begins on the next page.

APPENDIX A SENSOR PLACEMENT GUIDELINES

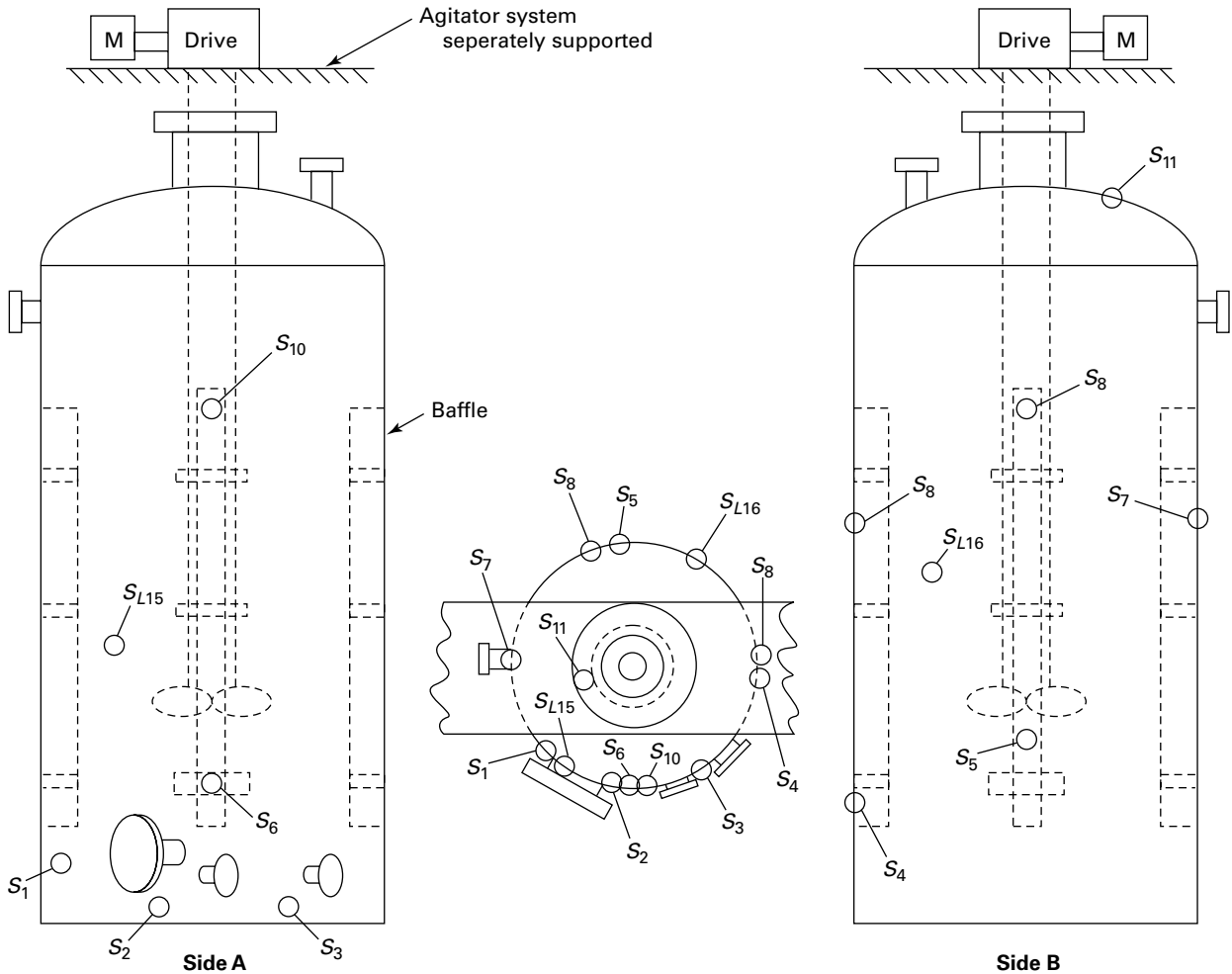
CASE 1 – ATMOSPHERIC VERTICAL VESSEL



GUIDELINES:

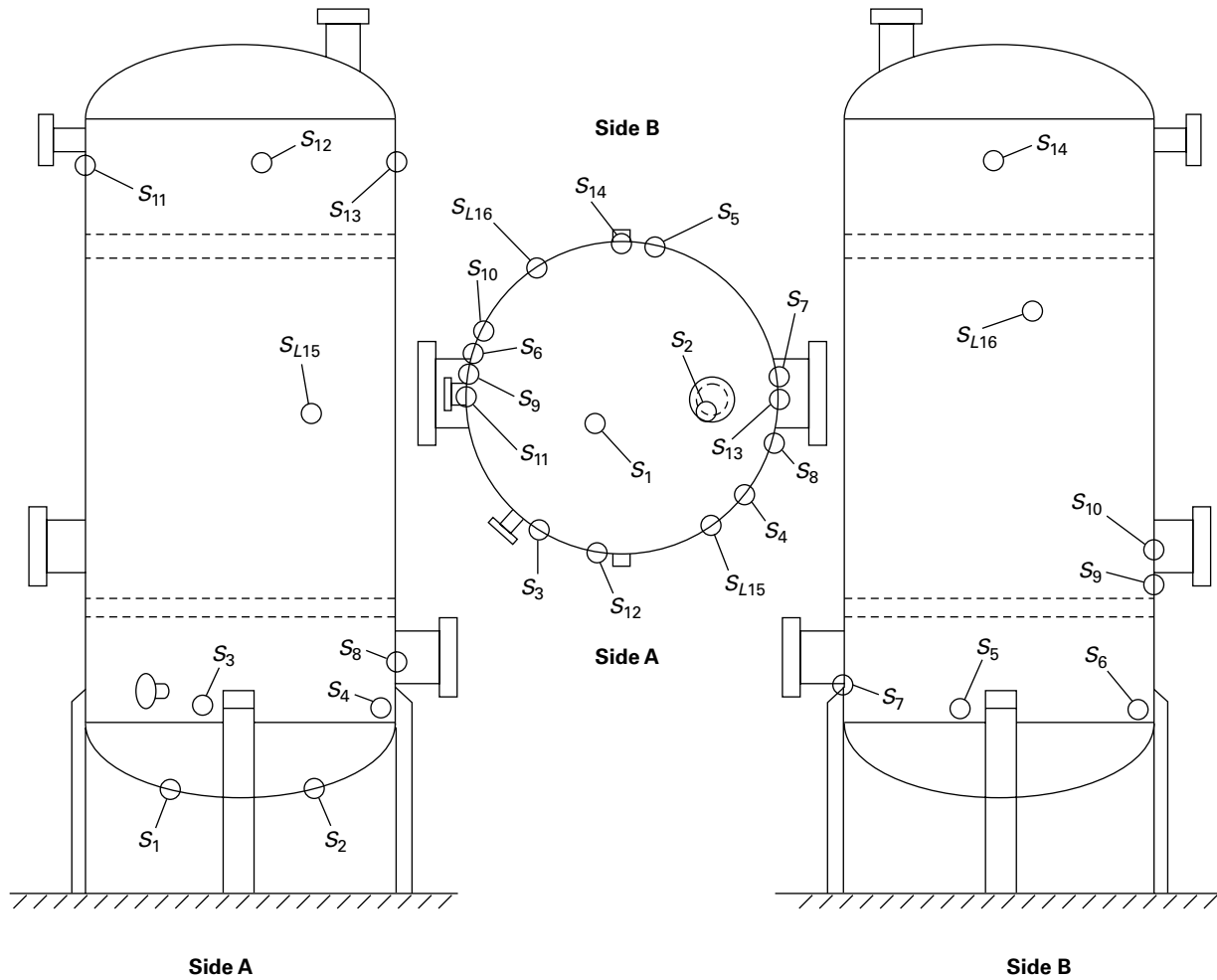
- (1) The bottom knuckle region is critical due to discontinuity stresses. Locate sensors to provide adequate coverage, e.g., approximately every 90 deg. and 6 in. to 12 in. (152 mm to 305 mm) away from knuckle on shell.
- (2) The secondary bond joint areas are suspect, e.g., nozzles, manways, shell butt joint, etc. For nozzles and manways, the preferred sensor location is 3 in. to 6 in. (76 mm to 152 mm) from intersection with shell and below. The shell butt joint region is important. Locate the two high frequency sensors up to 180 deg. apart—one above and one below the joint.
- (3) The low frequency sensors shown as S_{L15} and S_{L16} should be located at vessel mid-height—one above and one below the joint. Space as far apart as possible—up to 180 deg. and at 90 deg. to the high frequency pair.

CASE 2 – ATMOSPHERIC VERTICAL VESSEL

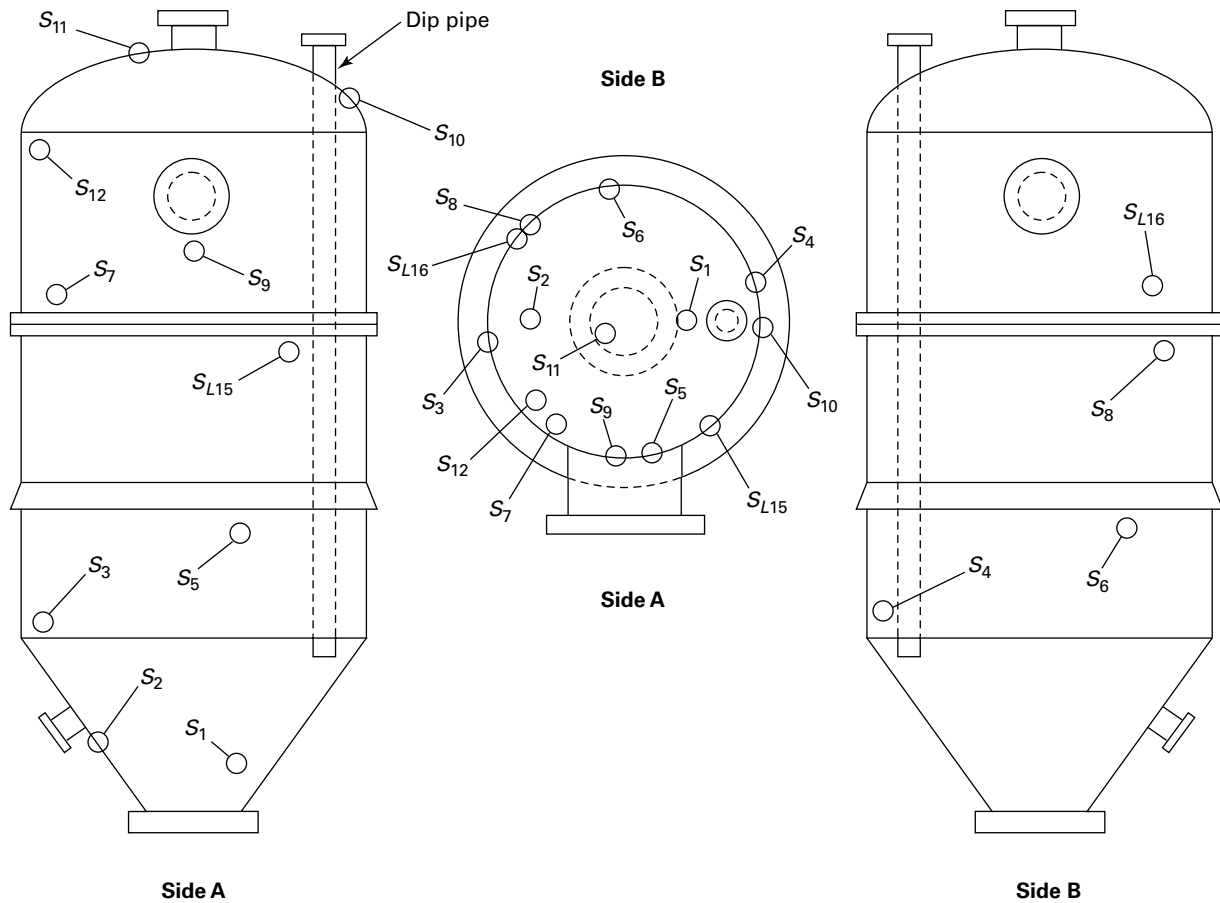


GUIDELINES:

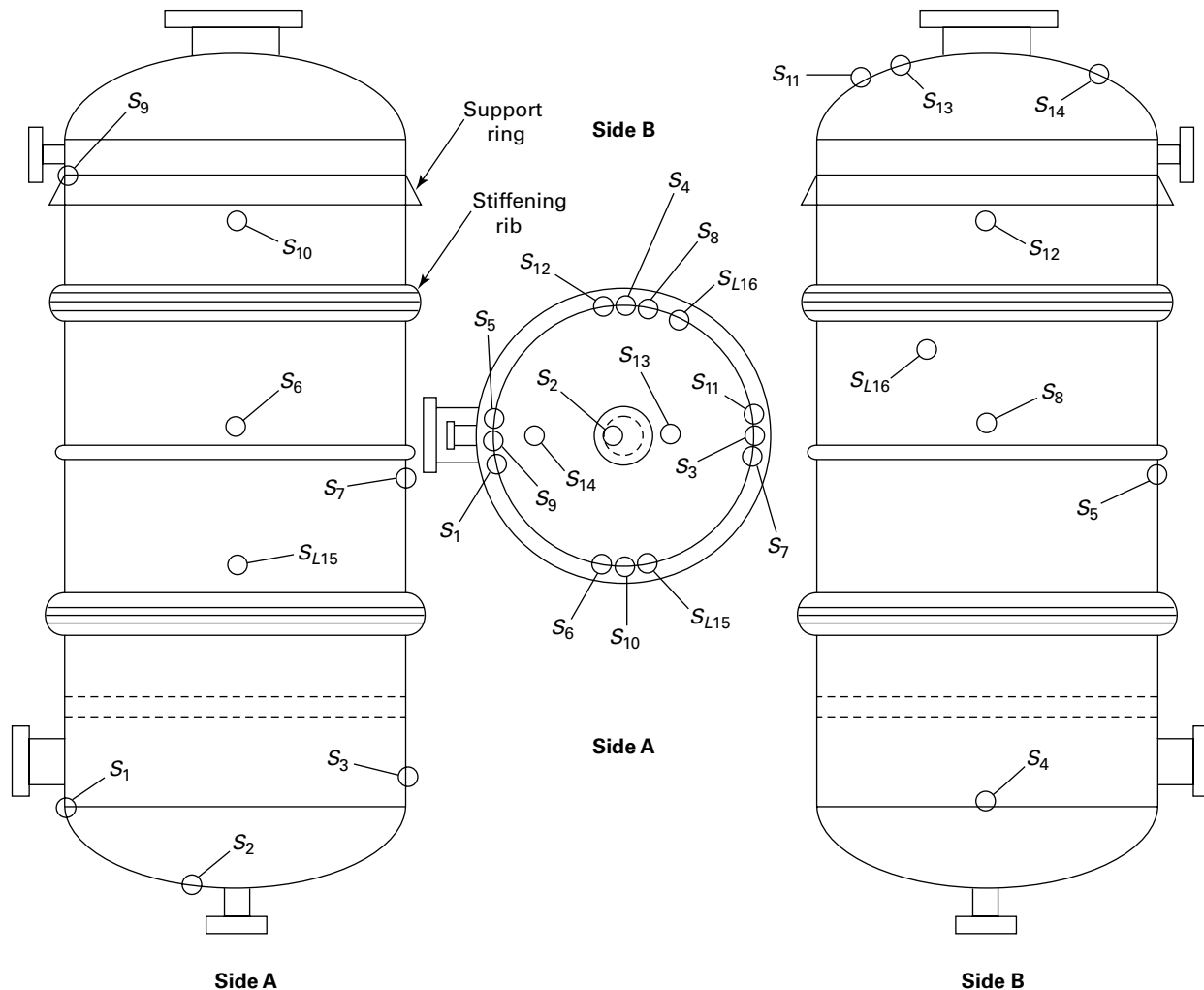
- (1) The bottom knuckle region is critical due to discontinuity stresses. Locate sensors to provide adequate coverage, e.g., approximately every 90 deg. and 6 in. to 12 in. (152 mm to 305 mm) away from the knuckle on shell. In this example, sensors are so placed that the bottom nozzles, manways, and baffle areas plus the knuckle regions are covered.
- (2) The secondary bond joint areas are suspect, e.g., nozzles, manways, and baffle attachments to shell. See the last sentence of above for bottom region coverage in this example. Note sensor adjacent to agitator shaft top manway. This region should be checked with agitator on.
- (3) The low frequency sensors shown as S_{L15} and S_{L16} should be located at vessel mid-height, one above and one below joint. They should be spaced as far apart as possible—up to 180 deg.

CASE 3 – ATMOSPHERIC / PRESSURE VESSEL**GUIDELINES:**

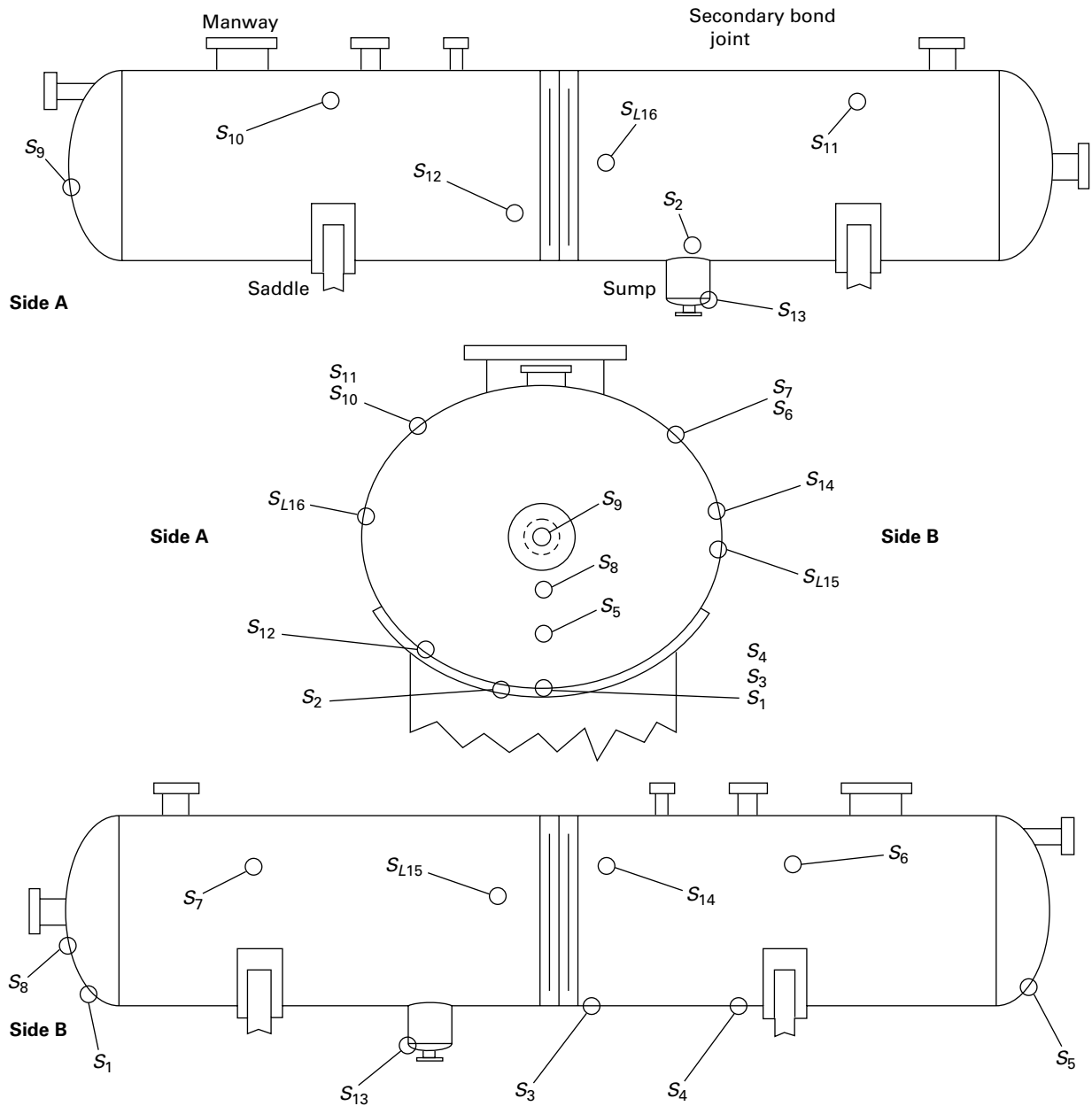
- (1) The bottom head is highly stressed. Locate two sensors approximately as shown.
- (2) The bottom knuckle region is critical. Locate sensors to provide adequate coverage, e.g., approximately every 90 deg. and 6 in. to 12 in. (152 mm to 305 mm) away from knuckle on shell. The top knuckle region is similarly treated.
- (3) The secondary bond areas are suspect, i.e., nozzles, manways, and leg attachments. For nozzles and manways, the preferred sensor location is 3 in. to 6 in. (76 mm to 152 mm) from the intersection with shell and below. For leg attachments, there should be a sensor within 12 in. of the shell-leg interface.
- (4) The low frequency sensors shown as S_{L15} and S_{L16} should be located at vessel mid-height—one above and one below joint. They should be spaced as far apart as possible up to 180 deg.

CASE 4 – ATMOSPHERIC / PRESSURE VERTICAL VESSEL**GUIDELINES:**

- (1) The secondary bond joint areas are suspect, i.e., nozzles, manways, and body flanges. Particularly critical in this vessel are the bottom manway and nozzle. For nozzles and manways, the preferred sensor location is 3 in. to 6 in. (76 mm to 152 mm) from intersection with shell and below. The bottom flange in this example is covered by sensor 3 in. to 6 in. (76 mm to 152 mm) above the manway. The body flange is covered by low frequency sensors S_{L15} and S_{L16} —one above and one below the body flange and spaced as far apart as possible—up to 180 deg. Displaced approximately 90 deg. from this pair and spaced up to 180 deg. apart are the two high frequency sensors—one above and one below the flange.
- (2) The knuckle regions are suspect due to discontinuity stresses. Locate sensors to provide adequate coverage, i.e., approximately every 90 deg. and 3 in. to 6 in. (76 mm to 152 mm) away from knuckle on shell.

CASE 5 – ATMOSPHERIC / VACUUM VERTICAL VESSEL**GUIDELINES:**

- (1) The knuckle regions are suspect due to discontinuity stresses. Locate sensors to provide adequate coverage, i.e., approximately every 90 deg. and 6 in. to 12 in. (152 mm to 305 mm) away from knuckle on shell.
- (2) The secondary bond joint areas are critical, e.g., nozzles, manways, and shell butt joints. For nozzles and manways, the preferred sensor location is 3 in. to 6 in. (76 mm to 152 mm) from the intersection with the shell (or head) and below, where possible. The shell butt joint region is important. Locate sensors up to 180 deg. apart where possible and alternately above and below joint.
- (2) The low frequency sensors shown as S_{L15} and S_{L16} should be located at vessel mid-height—one above and one below the joint. They should be spaced as far apart as possible—up to 180 deg. and at 90 deg. to other pair.

CASE 6 – ATMOSPHERIC / PRESSURE HORIZONTAL TANK**GUIDELINES:**

- (1) The discontinuity stresses at the intersection of the heads and the shell in the bottom region are important. Sensors should be located to detect structural problems in these areas.
- (2) The secondary bond joint areas are suspect, e.g., shell butt joint, nozzles, manways, and sump. The preferred sensor location is 3 in. to 6 in. (76 mm to 152 mm) from intersecting surfaces of revolution. The shell butt joint region is important. Locate the two high frequency sensors up to 180 deg. apart—one on either side of the joint.
- (3) The low frequency sensors shown as S_{L15} and S_{L16} should be located in the middle of the tank—one on either side of the joint. They should be spaced as far apart as possible, i.e., up to 180 deg. and at 90 deg. to high frequency pair.

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ARTICLE 12

ACOUSTIC EMISSION EXAMINATION OF METALLIC VESSELS DURING PRESSURE TESTING

T-1210 SCOPE

This Article describes methods for conducting acoustic emission (AE) examination of metallic pressure vessels during acceptance pressure testing when specified by a referencing Code Section. When AE examination in accordance with this Article is specified, the referencing Code Section shall be consulted for the following specific requirements:

- (a) personnel qualification/certification requirements;
- (b) requirements/extent of examination and/or volume(s) to be examined;
- (c) acceptance/evaluation criteria;
- (d) standard report requirements;
- (e) content of records and record retention.

When this Article is specified by a referencing Code Section, the AE method described in the Article shall be used together with Article 1, General Requirements. Definitions of terms used in this Article may be found in Mandatory Appendix III of this Article.

T-1220 GENERAL

T-1220.1 The principal objectives of AE examination are to locate and monitor emission sources caused by surface and internal discontinuities in the vessel wall, welds, and fabricated parts and components.

T-1220.2 All relevant indications caused by AE sources shall be evaluated by other methods of nondestructive examination.

T-1221 Vessel Stressing

Arrangements shall be made to stress the vessel using internal pressure as specified by the referencing Code Section. The rate of application of pressure shall be specified in the examination procedure and the pressurizing rate shall be sufficient to expedite the examination with minimum extraneous noise. Provisions

shall be made for holding the pressure at designated hold points.

T-1222 Noise Reduction

External noise sources such as rain, foreign objects contacting the vessel, and pressurizing equipment noise must be below the system examination threshold.

T-1223 Sensors

T-1223.1 Sensor Frequency. Selection of sensor frequency shall be based on consideration of background noise, acoustic attenuation, and vessel configuration. Frequencies in the range of 100 kHz–400 kHz have been shown to be effective. (See Nonmandatory Appendix B.)

T-1223.2 Sensor Mounting. The location and spacing of the sensors are referenced in T-1243. The sensors shall be acoustically coupled using couplant specified in the written procedure. Suitable adhesive systems are those whose bonding and acoustic coupling effectiveness have been demonstrated.

When examining austenitic stainless steels, titanium, or nickel alloys, the need to restrict chloride/fluoride ion content, total chlorine/fluorine content, and sulfur content in the couplant or other materials used on the vessel surface shall be considered and limits agreed upon between contracting parties.

The sensor shall be held in place utilizing methods of attachment, as specified in the written procedure.

The signal cable and preamplifier must be supported.

T-1223.3 Surface Contact. Sensors shall be mounted directly on the vessel surface, or on integral waveguides.

T-1224 Location of Acoustic Emission Sources

T-1224.1 Sources shall be located to the specified accuracy by multichannel source location, zone location, or both, as required by the referencing Code Section.

All hits detected by the instrument shall be recorded and used for evaluation.

T-1224.2 Multichannel source location accuracy shall be within a maximum of 2 component wall thicknesses or 5% of the sensor spacing distance, whichever is greater.

01 T-1225 Procedure Requirements

Acoustic emission examination shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable:

- (a) material and configurations to be examined, including dimensions and product form;
- (b) background noise measurements;
- (c) sensor type, frequency, and Manufacturer;
- (d) method of sensor attachment
- (e) couplant;
- (f) acoustic emission instrument type and filter frequency;
- (g) sensor locations;
- (h) method for selection of sensor locations;
- (i) description of system calibration(s);
- (j) data to be recorded and method of recording;
- (k) post-examination vessel cleaning;
- (l) report requirements; and
- (m) qualification/certification of the examiner(s).

T-1230 EQUIPMENT AND SUPPLIES

(a) The AE system consists of sensors, signal processing, display, and recording equipment (see Appendix I).

(b) Data measurement and recording instrumentation shall be capable of measuring the following parameters from each AE hit on each channel: counts above system examination threshold, peak amplitude, arrival time, and Measured Area of the Rectified Signal Envelope (MARSE). Mixing or otherwise combining the acoustic emission signals of different sensors in a common preamplifier is not permitted except to overcome the effects of local shielding. (See Nonmandatory Appendix B.) The data acquisition system shall have sufficient channels to provide the sensor coverage defined in T-1243.4. Amplitude distribution, by channel, is required for source characterization. The instrumentation shall be capable of recording the measured acoustic emission data by hit and channel number.

(c) Time and pressure shall be measured and recorded as part of the AE data. The pressure shall be continu-

ously monitored to an accuracy of $\pm 2\%$ of the maximum test pressure.

(1) Analog type indicating pressure gages used in testing shall be graduated over a range not less than $1\frac{1}{2}$ times nor more than 4 times the test pressure.

(2) Digital type pressure gages may be used without range restriction provided the combined error due to calibration and readability does not exceed 1% of the test pressure.

T-1240 APPLICATION REQUIREMENTS

T-1241 Equipment

(See T-1230 and Mandatory Appendix I.)

T-1242 System Calibration

(See Mandatory Appendix II.)

T-1243 Pre-Examination Measurements

T-1243.1 On-Site System Calibration. Prior to each vessel test or series of tests, the performance of each utilized channel of the AE instrument shall be checked by inserting a simulated AE signal at each main amplifier input.

A series of tests is that group of tests using the same examination system which is conducted at the same site within a period not exceeding 8 hr or the test duration, whichever is greater.

This device shall input a sinusoidal burst-type signal of measurable amplitude, duration, and carrier frequency. As a minimum, on-site system calibration shall be able to verify system operation for threshold, counts, MARSE, and peak amplitude. Calibration values shall be within the range of values specified in Appendix I.

T-1243.2 Attenuation Characterization. An attenuation study is performed in order to determine sensor spacing. This study is performed with the test fluid in the vessel using a simulated AE source. For production line testing of identical vessels see Nonmandatory Appendix B.

The typical signal propagation losses shall be determined according to the following procedure: select a representative region of the vessel away from manways, nozzles, etc., mount a sensor, and strike a line out from the sensor at a distance of 10 ft (3 m) if possible. Break 0.3 mm (2H) leads next to the sensor and then at a 2 ft (0.6 m) interval along this line. The breaks shall be done with the lead at an angle of approximately 30 deg. to the surface and with a 0.1 in. (2.5 mm) lead extension.

T-1243.3 Sensor Location. Sensor locations on the vessel shall be determined by the vessel configuration and the maximum sensor spacing (see T-1243.4). A further consideration in locating sensors is the need to detect structural flaws at critical sections, e.g., welds, high stress areas, geometric discontinuities, nozzles, manways, repaired regions, support rings, and visible flaws. Additional consideration should be given to the possible attenuation effects of welds. See Nonmandatory Appendix B. Sensor location guidelines for zone location for typical vessel types are given in Nonmandatory Appendix A.

T-1243.4 Sensor Spacing

T-1243.4.1 Sensor Spacing for Zone Location.

Sensors shall be located such that a lead break at any location in the examination area is detected by at least one sensor and have a measured amplitude not less than as specified by the referencing Code Section. The maximum sensor spacing shall be no greater than $1\frac{1}{2}$ times the threshold distance. The threshold distance is defined as the distance from a sensor at which a pencil-lead break on the vessel has a measured amplitude value equal to the evaluation threshold.

T-1243.4.2 Sensor Spacing for Multichannel Source Location Algorithms. Sensors shall be located such that a lead break at any location in the examination area is detected by at least the minimum number of sensors required for the algorithms.

T-1243.5 Systems Performance Check. A verification of sensor coupling and circuit continuity shall be performed following sensor mounting and system hookup and again immediately following the test. The peak amplitude response of each sensor to a repeatable simulated acoustic emission source at a specific distance from each sensor should be taken prior to and after the test. The measured peak amplitude should not vary more than 4 dB from the average of all the sensors. Any channel failing this check should be investigated and replaced or repaired as necessary. If during any check it is determined that the testing equipment is not functioning properly, all of the product that has been tested since the last valid system performance check shall be re-examined.

T-1244 Examination Procedure

T-1244.1 General Guidelines. The vessel is subjected to programmed increasing stress levels to a predetermined maximum while being monitored by sensors that detect acoustic emission caused by growing structural discontinuities.

T-1244.2 Background Noise. Extraneous noise must be identified, minimized, and recorded.

T-1244.2.1 Background Noise Check Prior to Loading. Acoustic emission monitoring of the vessel during intended examination conditions is required to identify and determine the level of spurious signals following the completion of the system performance check and prior to stressing the vessel. A recommended monitoring period is 15 min. If background noise is above the evaluation threshold, the source of the noise shall be eliminated or the examination terminated.

T-1244.2.2 Background Noise During Examination. In the AE examiner's analysis of examination results, background noise shall be noted and its effects on test results evaluated. Sources of background noise include:

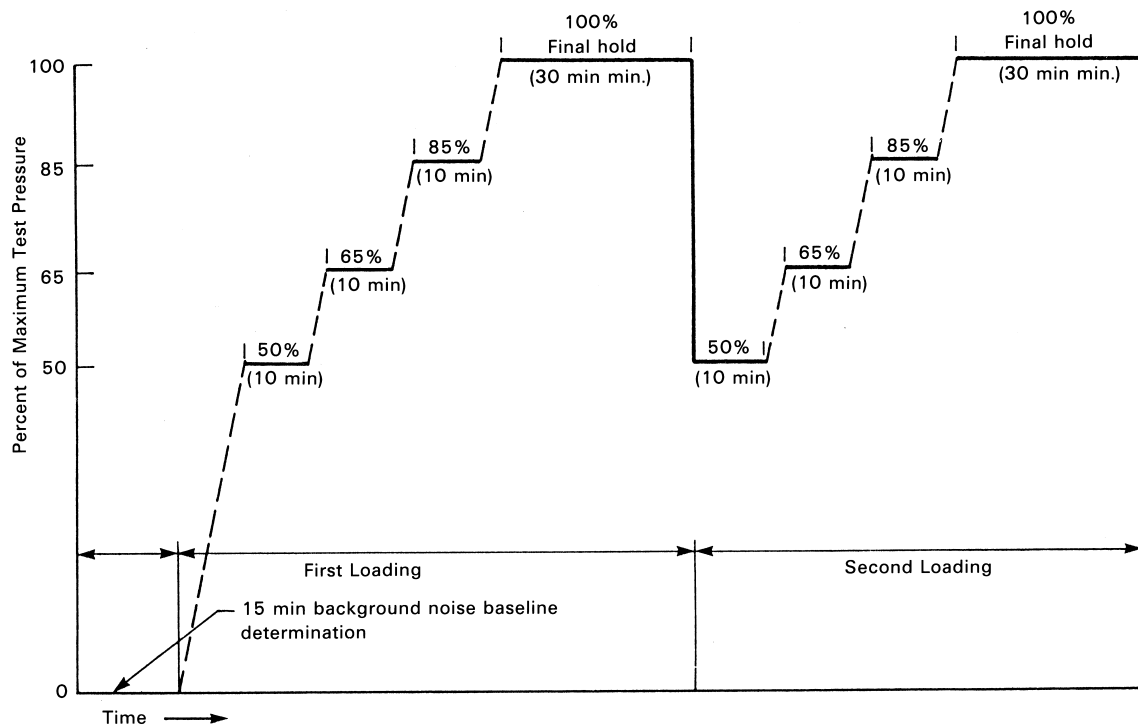
- (1) liquid splashing into a vessel;
- (2) a pressurizing rate that is too high;
- (3) pumps, motors, and other mechanical devices;
- (4) electromagnetic interference; and
- (5) environment (rain, wind, etc.).

Leaks from the vessel such as valves, flanges, and safety relief devices can mask AE signals from the structure. Leaks must be eliminated prior to continuing the examination.

T-1244.3 Vessel Pressurization

T-1244.3.1 Rates of pressurization, pressurizing medium, and safety release devices shall be as specified by the referencing Code Section. The pressurization should be done at a rate that will expedite the test with a minimum of extraneous noise.

T-1244.3.2 Pressurization Sequence. The examination shall be done in accordance with the referencing Code Section. Pressure increments shall generally be to 50%, 65%, 85%, and 100% of maximum test pressure. Hold periods for each increment shall be 10 min and for the final hold period shall be at least 30 min. (See Fig. T-1244.3.2.) Normally, the pressure test will cause local yielding in regions of high secondary stress. Such local yielding is accompanied by acoustic emission which does not necessarily indicate discontinuities. Because of this, only large amplitude hits and hold period data are considered during the first loading of vessels without post-weld heat treatment (stress relief). If the first loading data indicates a possible discontinuity or is inconclusive, the vessel shall be repressurized from 50% to 100% of the test pressure with intermediate load holds at 50%, 65%, and 85%. Hold periods for the second pressurization shall be the same as for the original pressurization.

**GENERAL NOTE:**

During loading, increases in pressure/load levels should not exceed 10% of the maximum test pressure in 2 min.

FIG. T-1244.3.2 AN EXAMPLE OF PRESSURE VESSEL TEST STRESSING SEQUENCE

T-1244.3.3 Test Termination. Departure from a linear count or MARSE vs. load relationship should signal caution. If the AE count or MARSE rate increases rapidly with load, the vessel shall be unloaded and either the test terminated or the source of the emission determined and the safety of continued testing evaluated. A rapidly (exponentially) increasing count or MARSE rate may indicate uncontrolled, continuing damage indicative of impending failure.

T-1260 CALIBRATION

(See Mandatory Appendix II.)

T-1280 EVALUATION

T-1281 Evaluation Criteria

The AE criteria shown in Table T-1281 are set forth as one basis for assessing the significance of AE

indications. These criteria are based on a specific set of AE monitoring conditions. The criteria to be used shall be as specified in the referencing Code Section.

T-1290 DOCUMENTATION

T-1291 Written Report

The report shall include the following:

- (a) complete identification of the vessel, including material type, method of fabrication, Manufacturer's name, and certificate number;
- (b) vessel sketch of Manufacturer's drawing with dimensions and sensor locations;
- (c) test fluid employed;
- (d) test fluid temperature;
- (e) test sequence load rate, hold times, and hold levels;
- (f) attenuation characterization and results;
- (g) record of system performance verifications;

TABLE T-1281
AN EXAMPLE OF EVALUATION CRITERIA FOR ZONE LOCATION

Emission During Load Hold		Count Rate	Number of Hits	Large Amplitude Hits	MARSE or Amplitude	Activity	Evaluation Threshold, dB
(First Loading) Pressure vessels without full postweld heat treatment	Not more than E_H hits beyond time T_H	Not applied	Not applied	Not more than E_A hits above a specified amplitude	MARSE or amplitudes do not increase with increasing load.	Activity does not increase with increasing load.	V_{TH}
Pressure vessels other than those covered above	Not more than E_H hits beyond time T_H	Less than M_T counts per sensor for a specified load increase	Not more than E_T hits above a specified amplitude	Not more than E_A hits above a specified amplitude	MARSE or amplitudes do not increase with increasing load.	Activity does not increase with increasing load.	V_{TH}

GENERAL NOTES:

- (a) E_H , M_T , E_T , and E_A are specified acceptance criteria values specified by the referencing Code Section.
 (b) V_{TH} is the specified evaluation threshold.
 (c) T_H is the specified hold time.

- (h) correlation of test data with the acceptance criteria;
- (i) a sketch or Manufacturer's drawings showing the location of any zone not meeting the evaluation criteria;
- (j) any unusual effects or observations during or prior to the test;
- (k) date(s) of test(s);
- (l) name(s) and qualifications of the test operator(s); and
- (m) complete description of AE instrumentation including Manufacturer's name, model number, sensor type, instrument settings, calibration data, etc.

T-1292 Record

- (a) A permanent record AE data includes:
 - (1) AE hits above threshold vs time and/or pressure for zones of interest;
 - (2) total counts vs time and/or pressure; and
 - (3) written reports.
- (b) The AE data shall be maintained with the records of the vessel.

ARTICLE 12

MANDATORY APPENDICES

APPENDIX I — INSTRUMENTATION PERFORMANCE REQUIREMENTS

I-1210 ACOUSTIC EMISSION SENSORS

I-1210.1 General. Acoustic emission sensors in the range of 100 kHz–400 kHz shall be temperature-stable over the range of intended use, and shall not exhibit sensitivity changes greater than 3 dB over this range as guaranteed by the Manufacturer. Sensors shall be shielded against radio frequency and electromagnetic noise interference through proper shielding practice and/or differential (anticoincident) element design. Sensors shall have a frequency response with variations not exceeding 4 dB from the peak response.

I-1210.2 Sensor Characteristics. Sensors shall have a resonant response between 100 kHz–400 kHz. Minimum sensitivity shall be –80 dB referred to 1 volt/microbar, determined by face-to-face ultrasonic test.

NOTE: This method measures relative sensitivity of the sensor. Acoustic emission sensors used in the same test should not vary in peak sensitivity more than 3 dB from the average.

I-1220 SIGNAL CABLE

The signal cable from sensor to preamplifier shall not exceed 6 ft (1.8 m) in length and shall be shielded against electromagnetic interference.

I-1230 COUPLANT

Couplant selection shall provide consistent coupling efficiency during a test. Consideration should be given to testing time and the surface temperature of the vessel. The couplant and method of sensor attachment shall be specified in the written procedure.

I-1240 PREAMPLIFIER

The preamplifier shall be mounted in the vicinity of the sensor, or in the sensor housing. If the preamplifier is of differential design, a minimum of 40 dB of common-mode noise rejection shall be provided. Frequency response shall not vary more than 3 dB over the operating frequency and temperature range of the sensors.

I-1250 FILTER

Filters shall be of the band pass or high pass type and shall provide a minimum of 24 dB/octave signal attenuation. Filters shall be located in preamplifier. Additional filters shall be incorporated into the processor. Filters shall insure that the principal processing frequency corresponds to the specified sensor frequency.

I-1260 POWER-SIGNAL CABLE

The cable providing power to the preamplifier and conducting the amplified signal to the main processor shall be shielded against electromagnetic noise. Signal loss shall be less than 1 dB per 100 ft (30.5 m) of cable length. The recommended maximum cable length is 500 ft (152 m) to avoid excessive signal attenuation.

I-1270 POWER SUPPLY

A stable grounded electrical power supply, meeting the specifications of the instrumentation, shall be used.

I-1280 MAIN AMPLIFIER

The gain in the main amplifier shall be linear within 3 dB over the temperature range of 40°F to 125°F (4°C to 52°C).

I-1290 MAIN PROCESSOR**I-1291 General**

The main processor(s) shall have processing circuits through which sensor data will be processed. It shall be capable of processing hits, counts, peak amplitudes, and MARSE on each channel.

(a) *Threshold.* The AE instrument used for examination shall have a threshold control accurate to within ± 1 dB over its useful range.

(b) *Counts.* The AE counter circuit used for examination shall detect counts over a set threshold within an accuracy of $\pm 5\%$.

(c) *Hits.* The AE instrument used for examination shall be capable of measuring, recording, and displaying a minimum of 20 hits/sec total for all channels for a minimum period of 10 sec and continuously measuring, recording, and displaying a minimum of 10 hits/sec total for all channels. The system shall display a warning if there is greater than a 5 sec lag between recording and display during high data rates.

(d) *Peak Amplitude.* The AE circuit used for examination shall measure the peak amplitude with an accuracy of ± 2 dB.

(e) *Energy.* The AE circuit used for examination shall measure MARSE with an accuracy of $\pm 5\%$. The usable dynamic range for energy shall be a minimum of 40 dB.

(f) *Parametric Voltage.* If parametric voltage is measured by the AE instrument, it should measure to an accuracy of 2% of full scale.

I-1292 Peak Amplitude Detection

Comparative calibration must be established per the requirements of Appendix II. Usable dynamic range shall be a minimum of 60 dB with 1 dB resolution over the frequency band width of 100 kHz to 400 kHz, and the temperature range of 40°F to 125°F (4°C to 52°C). Not more than 2 dB variation in peak detection accuracy shall be allowed over the stated temperature range. Amplitude values shall be stated in dB, and must be referenced to a fixed gain output of the system (sensor or preamplifier).

**APPENDIX II —
INSTRUMENT CALIBRATION AND
CROSS-REFERENCING**

II-1210 MANUFACTURER'S CALIBRATION

Acoustic emission system components will be provided from the Manufacturer with certification of performance specifications and tolerances.

II-1211 Annual Calibration

The instrument shall have an annual comprehensive calibration following the guidelines provided by the Manufacturer using calibration instrumentation meeting the requirements of a recognized national standard.

II-1220 INSTRUMENT CROSS-REFERENCING

The performance and threshold definitions vary for different types of AE instrumentation. Parameters such as counts, amplitude, energy, etc., vary from Manufacturer to Manufacturer and from model to model by the same Manufacturer. This section of appendix describes techniques for generating common baseline levels for the different types of instrumentation.

The procedures are intended for baseline instrument calibration at 60°F to 80°F (16°C to 27°C). For field use, small portable signal generators and calibration transducers can be carried with the equipment and used for periodic checking of sensor, preamplifier, and channel sensitivity.

II-1221 Sensor Characterization

Threshold of acoustic emission detectability is an amplitude value. All sensors shall be furnished with documented performance data. Such data shall be traceable to NBS standards. A technique for measuring threshold of detectability is described in Article XI, Appendix II.

**APPENDIX III — GLOSSARY OF
TERMS FOR ACOUSTIC EMISSION
EXAMINATION OF METAL
PRESSURE VESSELS**

III-1210 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms

relating to metal pressure vessel examination with acoustic emission.

III-1220 GENERAL REQUIREMENTS

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 defines the terms that are used in conjunction with this Article.

(c) For general terms, such as *Interpretation*, *Flaw*, *Discontinuity*, *Evaluation*, etc., refer to Article 1, Mandatory Appendix I.

(d) In addition to those terms listed in SE-1316, the terms listed in II-1230 are also applicable.

III-1230 REQUIREMENTS

The following Code terms are used in conjunction with this Article:

dB scale — a relative logarithmic scale of signal amplitude defined by $\text{dB } V = 20 \log V^{\text{in}}/V^{\text{out}}$. The reference voltage is defined as 1 volt out of the sensor and V is measured amplitude in volts.

electronic waveform generator — a device which can repeatably induce a transient signal into an acoustic emission processor for the purpose of checking, verifying, and calibrating the instrument

measured area of the rectified signal envelope — a measurement of the area under the envelope of the rectified linear voltage time signal from the sensor

multi-channel source location — a source location technique which relies on stress waves from a single source producing hits at more than one sensor. Position of the source is determined by mathematical algorithms using difference in time of arrival

simulated AE source — a device which can repeatedly induce a transient elastic stress wave into the structure

threshold of detectability — a peak amplitude measurement used for cross calibration of instrumentation from different vendors

zone — the area surrounding a sensor from which AE sources can be detected

zone location — a method of locating the approximate source of emission

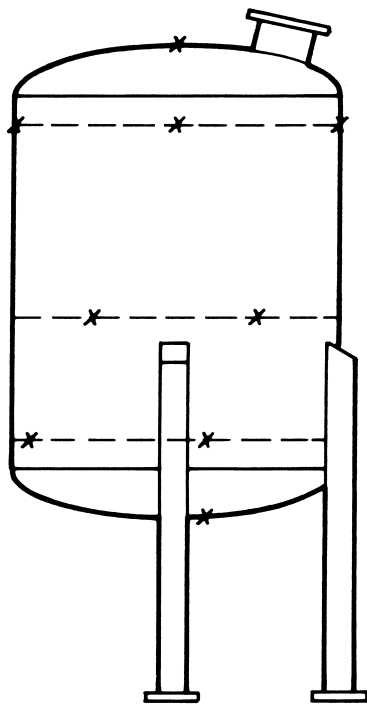
ARTICLE 12

NONMANDATORY APPENDICES

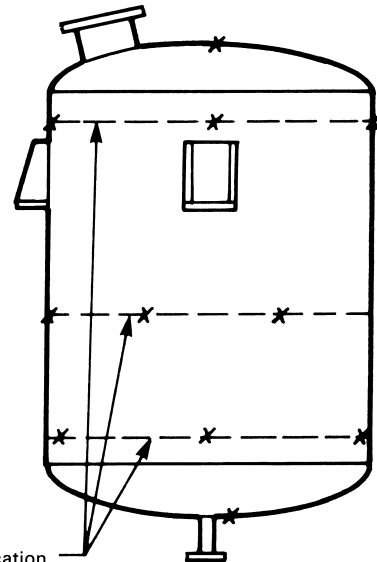
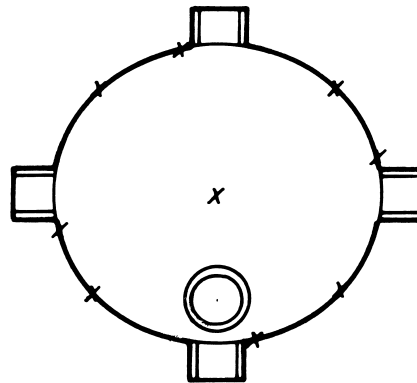
Appendix A begins on the next page.

APPENDIX A
SENSOR PLACEMENT GUIDELINES

**CASE 1 — VERTICAL PRESSURE VESSEL DISHED HEADS,
LUG OR LEG SUPPORTED**



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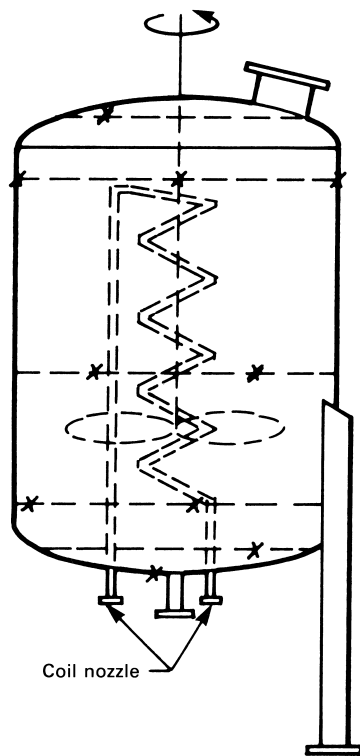


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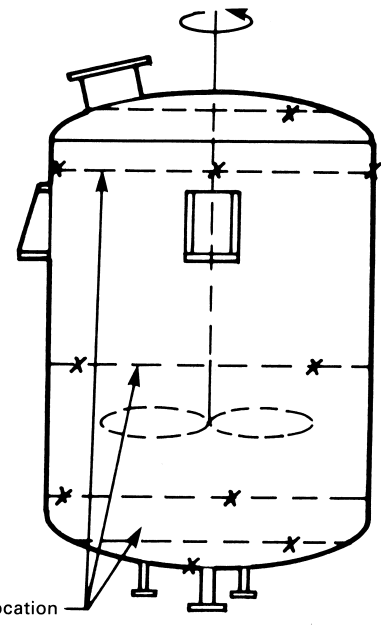
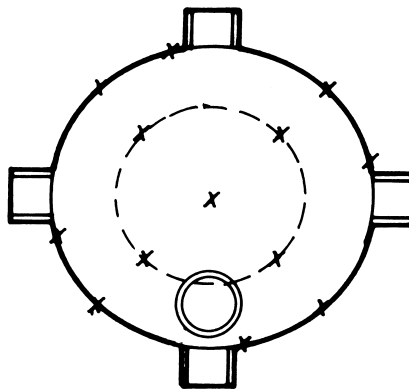
GUIDELINES:

- (1) X denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).
- (2) Additional rows of sensors may be required.

**CASE 2 — VERTICAL PRESSURE VESSEL DISHED HEADS,
AGITATED, BAFFLED LUG, OR LEG SUPPORT**



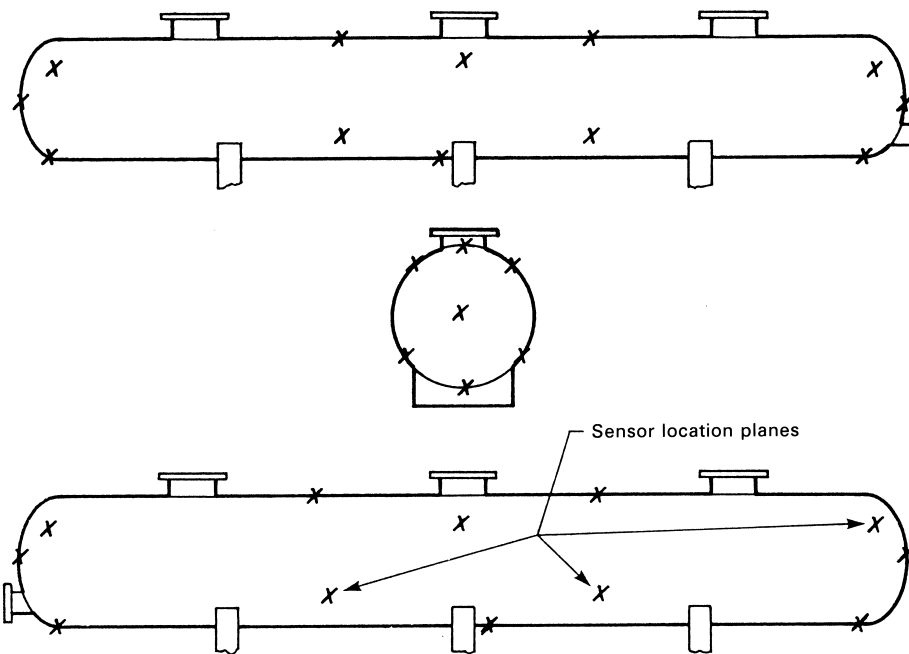
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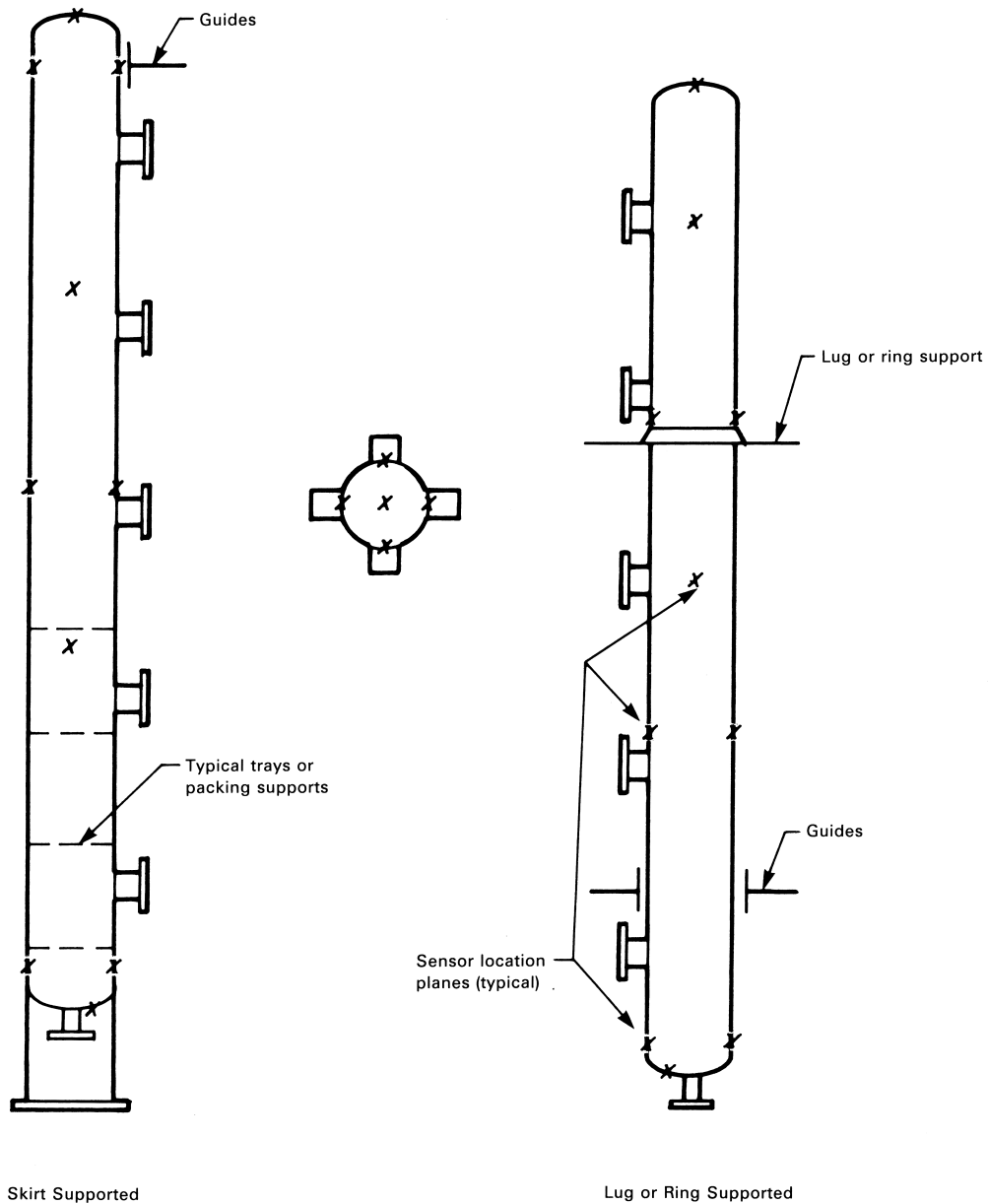
GUIDELINES:

- (1) X denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).
- (2) Sensors may be located on outlet to detect defects in coil.
- (3) Additional rows of sensors may be required.

CASE 3 — HORIZONTAL PRESSURE VESSEL DISHED HEADS, SADDLE SUPPORTED**GUIDELINES:**

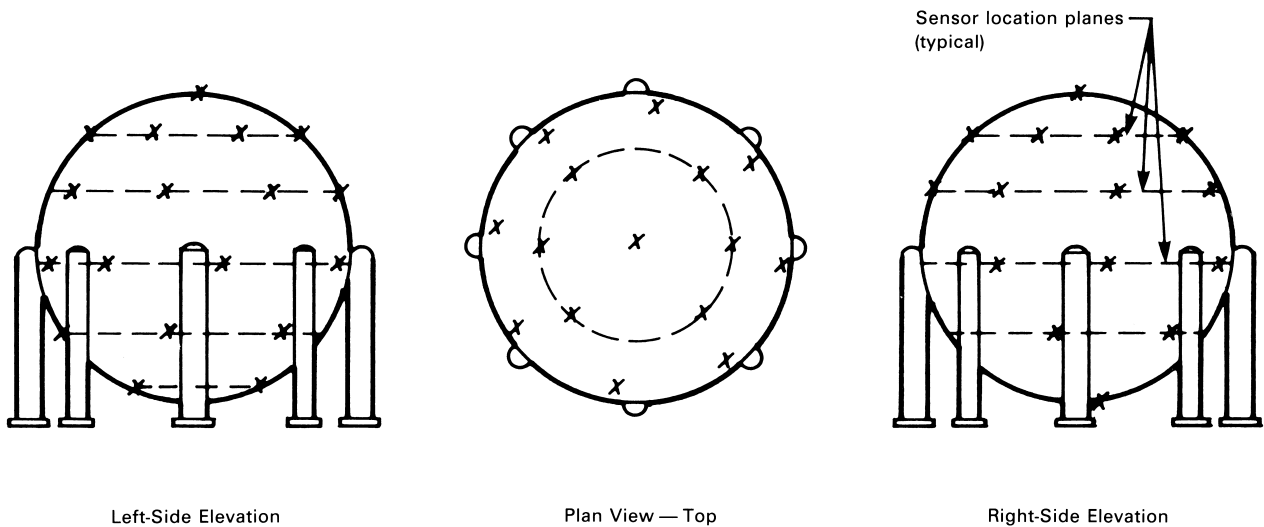
- (1) X denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).
- (2) Additional rows of sensors may be required.

**CASE 4 — VERTICAL PRESSURE VESSEL PACKED OR TRAYED COLUMN DISHED HEADS,
LUG OR SKIRT SUPPORTED**



GUIDELINES:

- (1) X denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).
- (2) Special areas may require additional sensors.
- (3) Additional rows of sensors may be required.

CASE 5 — SPHERICAL PRESSURE VESSEL, LEG SUPPORTED**GUIDELINES:**

- (1) X denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).
- (2) Additional sensors may be required.

APPENDIX B — SUPPLEMENTAL INFORMATION FOR CONDUCTING ACOUSTIC EMISSION EXAMINATIONS

B-10 FREQUENCY SELECTION

The frequency band of 100 kHz–200 kHz is the lowest frequency band that should be considered for general AE pressure vessel examination. Higher frequency bands may be considered if background noise cannot be eliminated. If a higher frequency band is used the following items must be considered.

- (a) Attenuation characteristics will change.
- (b) Sensor spacings will decrease and more sensors will be required to adequately cover the evaluation area.
- (c) Instrumentation performance requirements described in Appendix I must be adjusted to the higher frequency band.
- (d) Instrumentation calibration described in Appendix II must be performed at the higher frequency band.
- (e) Alternate evaluation/acceptance criteria must be obtained from the referencing Code Section.

B-20 COMBINING MORE THAN ONE SENSOR IN A SINGLE CHANNEL

Two or more sensors (with preamplifiers) may be plugged into a single channel to overcome the effects of local shielding in a region of the vessel. One specific

example of this is the use of several sensors (with preamplifiers around a manway or nozzle).

B-30 ATTENUATIVE WELDS

Some have been shown to be highly attenuative to non-surface waves. This situation predominantly affects multichannel source location algorithms. This situation can be identified by modifying the attenuation characterization procedure to produce a stress wave which does not contain surface waves traveling across the weld.

B-40 PRODUCTION LINE TESTING OF IDENTICAL VESSELS

For situations which involve repeated tests of identical vessels where there is no change in the essential variables such as material, thickness, product form and type, the requirement for attenuation characterization on each vessel is waived.

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ARTICLE 13

CONTINUOUS ACOUSTIC EMISSION MONITORING

T-1310 SCOPE

This Article describes requirements to be used during continuous acoustic emission (AE) monitoring of metal or non-metal pressure boundary components used for either nuclear or non-nuclear service. Monitoring may be performed as a function of load, pressure, temperature, and/or time.

When AE monitoring in accordance with this Article is required, the referencing Code Section should specify the following:

- (a) personnel qualification/certification requirements
- (b) extent of examination and/or area(s)/volume(s) to be monitored
- (c) duration of monitoring period
- (d) acceptance/evaluation criteria
- (e) reports and records requirements

When this Article is specified by a referencing Code section, the technical requirements described herein shall be used together with Article 1, General Requirements. Definitions of terms used in this Article are in Mandatory Appendix VII of this Article.

Generic requirements for continuous acoustic emission monitoring of pressure boundary components during operation are addressed within this Article. Supplemental requirements for specific applications such as nuclear components, non-metallic components, monitoring at elevated temperatures, limited zone monitoring, lead detection, etc., are provided in the Mandatory Appendices to this Article.

T-1311 References

- SE-650, Standard Guide for Mounting Piezoelectric Acoustic Emission Sensors
- SE-976, Standard Guide for Determining the Reproducibility of Acoustic Emission Sensor Response
- SE-1211, Standard Practice for Leak Detection and Location using Surface-Mounted Acoustic Emission Sensors
- SE-1316, Standard Terminology for Nondestructive Examinations

SE-1419, Standard Test Method for Examination of Seamless, Gas-Filled Pressure Vessels Using Acoustic Emission

ASTM E 750-88 (1993), Standard Practice for Characterizing Acoustic Emission Instrumentation

ASTM E 1067-89 (1991), Standard Practice for Acoustic Emission Examination of Fiberglass Reinforced Plastic Resin (FRP) Tanks/Vessels

ASTM E 1118-89, Standard Practice for Acoustic Emission Examination of Reinforced Thermosetting Resin Pipe (RTRP)

ASTM E 1139-92, Standard Practice for Continuous Monitoring of Acoustic Emission from Metal Pressure Boundaries

T-1320 GENERAL

T-1321 Monitoring Objectives

The objectives of AE examination are to detect, locate, and characterize AE sources, and interpret the AE response signals to evaluate significance relative to pressure boundary integrity. These AE sources are limited to those activated during normal plant system operation, i.e., no special stimulus is applied exclusively to produce AE. In the context of this Article, normal system operation may include routine pressure tests performed during plant system shutdown.

T-1322 Relevant Indications

All relevant indications detected during AE monitoring should be evaluated by other methods of nondestructive examination.

T-1323 Personnel Qualification

T-1323.1 Procedures and Equipment Installation. All procedures used for qualifying, calibrating, installing, and operating the AE equipment, and for data analysis activities, shall be approved by a certified AE Level III.

Installation, calibration, and checkout of the AE equipment shall be performed under the direction of a certified AE Level III.

T-1323.2 AE System Operation. Routing operation of the AE system for collection and interpretation of data may be performed by competent personnel that are not necessarily AE specialists. However, AE system operation and data interpretation shall be verified by a certified AE Level III on approximately monthly intervals or more often if the system appears to be malfunctioning, relevant signals are detected, or an abrupt change in the rate of AE signals is observed.

T-1324 Component Stressing

Several means of stressing are applicable to AE examination including startup, continuous and cyclic operation, and shut-down of operating plant systems and components, as well as pressure tests of non-operating plant systems. Stress may be induced by either pressure or thermal gradients or a combination of both. It is the intent of this Article to describe examination techniques that are applicable during normal operation of pressurized plant system or component. During startup, the pressurizing rate should be sufficient to facilitate the examination with minimum extraneous noise. If appropriate, provisions should be made for maintaining the pressure at designated hold points. Advice on the use of compressed gas as a pressurizing medium is contained in SE-1419.

T-1325 Noise Interference

Noise sources that interfere with AE signal detection should be controlled to the extent possible. For continuous monitoring, it may be necessary to accommodate background noise by monitoring at high frequencies, shielding open AE system leads, using differential sensors, and using special data filtering techniques to reduce noise interference.

T-1326 Coordination With Plant System Owner/Operator

Due to operational considerations unique to the AE method, close coordination between the AE monitor operator and the owner/operator of the plant should be established and maintained. Provisions for this coordination function should be described in the written procedures submitted for approval prior to initiation of AE monitoring activities.

T-1327 Source Location and Sensor Mounting

Sources shall be located with the specified accuracy by multichannel sensor array, zone location, or both. As required by the referencing Code section, requirements for sensor mounting, placement, and spacing are further defined in the applicable Appendix.

T-1330 EQUIPMENT

T-1331 General

The AE system will consist of sensors, preamplifiers, amplifiers, filters, signal processors, and a data storage device together with interconnecting cables. Simulated AE source(s) and auxiliary equipment such as pressure and temperature inputs are also required. The AE monitoring system shall provide the functional capabilities shown in Fig. T-1331.

T-1332 Sensors

Sensors shall be one of two general types — those mounted directly on the surface of the component being monitored and those that are separated from the surface of the component by a connecting waveguide. Sensors shall be acoustically coupled to the surface of the component being monitored and be arranged in arrays capable of providing AE signal detection and source location to the required accuracy. Selection of sensor type shall be based on the application; i.e., low or high temperature, nuclear or non-nuclear, etc. The sensor selected for a specific application shall be identified in the procedure prepared for that application. The sensor system (i.e., sensors, preamplifiers, and connecting cables) used to detect AE shall limit electromagnetic interference to a level not exceeding 0.7 V peak after 90 dB amplification.

T-1332.1 Sensor Response Frequency. For each application, selection of the sensor response frequency shall be based on a characterization of background noise in terms of amplitude vs. frequency. The lowest frequency compatible with avoiding interference from background noise should be used to maximize sensitivity of AE signals and minimize signal attenuation.

T-1332.2 Differential and Tuned Sensors. Two sensor designs have been effective in overcoming noise interference problems. One is a differential sensor that operates to cancel out electrical transients entering the system through the sensor. The other is an inductively tuned sensor that operates to shape the sensor response around a selected frequency; i.e., inductive tuning allows

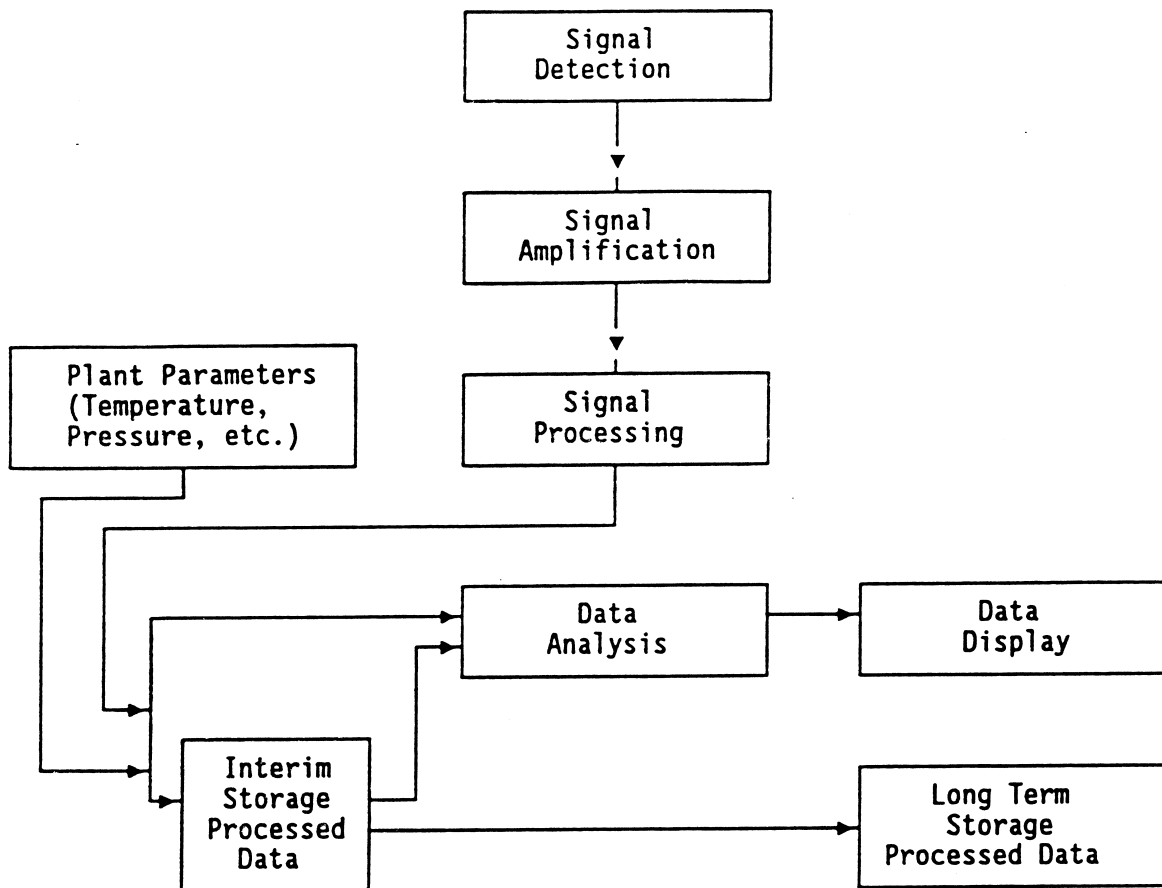


FIG. T-1331 FUNCTIONAL FLOW DIAGRAM — CONTINUOUS AE MONITORING SYSTEM

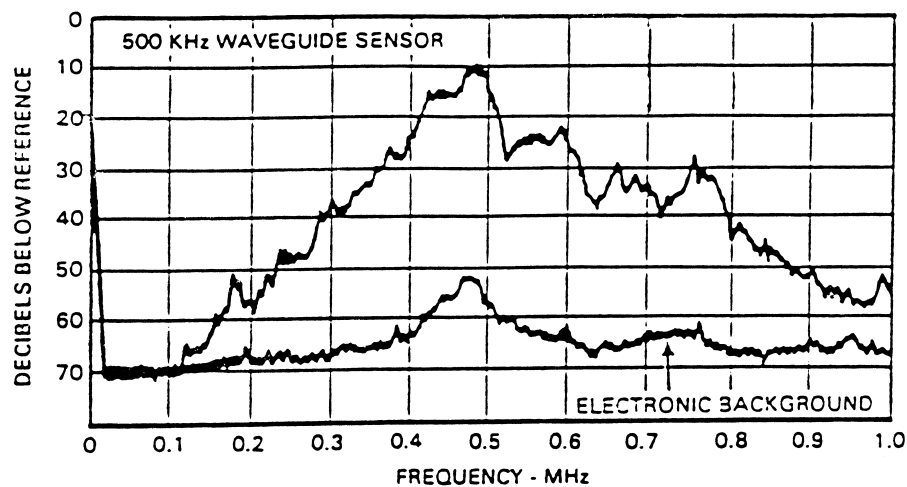


FIG. T-1332.2 RESPONSE OF A WAVEGUIDE AE SENSOR INDUCTIVELY TUNED TO 500 kHz

discrimination against frequencies on either side of a selected response frequency as shown in Fig. T-1332.2. These sensor designs may be used separately or together.

T-1332.3 Sensor Mounting. Sensors shall be mounted to the component surface using two basic methods. One is to bond the sensor directly to the surface with an adhesive. Temperature and vibration can adversely affect the bond between the sensor and the surface being monitored. Also, the chemical content of the adhesive shall be checked to assure that it is not deleterious to the surface of the component.

The second method for mounting a sensor employs pressure coupling using either a strap or a magnetic mount. A thin, soft metal interface layer between the sensor and the surface is often effective for achieving acoustic coupling with minimal pressure. In the case of waveguide sensors, the tip of the waveguide may be shaped to reduce the required force to maintain acoustic coupling.

T-1333 Signal Cables

Coaxial cables shall be used to conduct the AE signals from the sensors to the monitoring instrument (monitor). Whenever a protective barrier or containment structure must be penetrated using a bulkhead fitting or penetration plug to transmit signals from the sensor to the monitor, extreme care must be taken to avoid incurring excessive signal loss or noise. When the coaxial (signal) cables are used to supply DC power to the preamplifiers/line drivers, they should be terminated with the appropriate characteristic impedance.

T-1334 Amplifiers

At least one preamplifier shall be used with each sensor to amplify the AE signals for transmission to the monitor. Where long signal cables are required, a preamplifier and line driver between the sensor and the monitor may be needed.

With the high signal amplification required to detect AE signals, the internal noise of the preamplifiers must be minimized to avoid interference with AE signal detection. The frequency response band of the amplifiers shall be matched to the response profile determined for the AE sensors.

T-1335 AE Monitor

The AE monitor shall include a post amplifier, a signal identification function, and a signal processing module for each signal channel. The monitor shall also

include a video display function that can be used at the operator's discretion to display AE data as well as a data storage capability suitable for long term, nonvolatile data storage. A data analysis function may be integral with the AE monitor or be a separate function that draws from the stored AE data.

The post amplifier shall meet the requirements of T-1334. The AE monitor shall be capable of processing and recording incoming data at a rate of at least 50 hits/sec for all channels simultaneously for an indefinite time period and at a rate of at least 100 hits/sec for all channels simultaneously for any 15 sec period.

T-1335.1 AE Signal Identification. A real-time signal discrimination function to process incoming signals and identify relevant AE signals shall be included. The discrimination function may either exclude all signals not identified as AE from crack growth, or flag those signals identified as crack growth AE while accepting all signals above the voltage threshold.

T-1335.2 Signal Processing. The dynamic range of the signal processor shall be at least 36 dB for each parameter being measured. The signal processor shall be controlled by voltage threshold circuits that limit accepted data to signals that exceed the voltage amplitude threshold. The voltage threshold shall be determined on the basis of the background noise.

Signal parameters to be measured shall include AE hit count, total number of signal hits at each sensor, signal peak amplitude, time for threshold crossing to signal peak, measured area under the rectified signal envelope (MARSE) in V-secs, and difference in time of signal arrival (δt) at all sensors in a sensor array used for AE source location. In addition to the AE signal features above, clock time, date, and the value of plant parameters (internal pressure, temperature, etc., that can be identified as significant to crack growth) associated with the time of signal detection shall be recorded for each signal. The signal processor section shall also measure the overall RMS background signal level for each sensing channel for leak detection purposes.

T-1335.3 Data Storage. Data storage shall be nonvolatile and capable of storing the data described in T-1335.2 continuously over time periods of several weeks to several months depending on the application. One recording method that has proven satisfactory for continuous monitoring is a digital tape recorder using $\frac{1}{4}$ in. (6 mm), 16 track digital tape cartridges.

T-1335.4 Data Analysis and Display. The data analysis function of the AE monitor shall determine the location of AE sources as specified in the procedure

(T-1350). Location accuracies within one wall thickness of the pressure boundary or 5% of the minimum sensor spacing, whichever is greater, are typical for metal components.

The data analysis function shall be capable of providing a display and plot of selected AE information (e.g., AE events, crack growth AE from a given source area, AE energy) vs. plant system parameters and vs. time for correlation evaluations. Data analysis shall also provide continuous assessment of RMS signal level information derived from the signal measurement section.

The AE monitor system shall provide a means of presenting analyzed data; either a computer printout or a printout in conjunction with a video display. When the AE rate from an array exceeds the rate specified in the written procedure, the system shall activate an operator alert and identify the sensor array producing the high AE rate.

T-1340 REQUIREMENTS

T-1341 Equipment Qualification

Acceptable performance, including dynamic range, of the complete AE monitor (without sensors) shall be verified using an electronic waveform generator prior to installation. Sinusoidal burst signals from the waveform generator shall be input of each preamplifier to verify that the signal amplification, data processing functions, data processing rate, and data analysis, display, and storage meet the requirements of this Article. (NOTE: AE signal source location performance is tested under T-1362.1.) With the AE monitor gain set at operating level, the system shall be evaluated using input signals that will test both the low and high ends of the dynamic range of the AE monitor system. Signal frequencies shall include samples within the range of intended use.

T-1342 Sensor Qualification

T-1342.1 Sensor Sensitivity and Frequency Response. Each sensor shall produce a minimum signal of $0.1 \text{ mV}_{\text{peak}}$ referred to the sensor output at the selected monitoring frequency when mounted on a calibration block and excited with a helium gas jet as described in SE-976. Appropriate calibration blocks are identified in the Appendices as a function of specific applications. Helium gas excitation shall be performed using a 30 psi (207 KPa) helium source directed onto the surface of the calibration block through a #18 hypodermic needle held perpendicular to the calibration block surface. The needle tip shall be $\frac{1}{8}$ in. (3.2 mm)

above the surface of the block and $1\frac{1}{2}$ in. (38 mm) from the mounted sensor. The process may also be used to verify the sensor response profile in terms of frequency to assure that the response roll-off on either side of the selected monitoring frequency is acceptable.

An optional technique for determining the reproducibility of AE sensor response is referred to as the "Pencil Lead Break" technique, which is described in SE-976.

T-1342.2 Uniformity of Sensor Sensitivity. The sensitivity of each sensor shall be evaluated by mounting it on a calibration block as it will be mounted on the plant component and measuring its response to the energy produced by fracturing a 0.3-mm, 2H pencil lead against the surface of the block in accordance with SE-976 at a point 4 in. (102 mm) from the center of the sensor. When performing this evaluation, it is useful to use a 40 dB preamplifier with the sensor to produce an adequate output signal for accurate measurement. The peak response of each sensor to the simulated AE signal shall not vary more than 3 dB from the average for all sensors at the selected monitoring frequency.

T-1343 Signal Pattern Recognition

If AE signal pattern recognition is used, this function shall be demonstrated and qualified as follows:

(a) Assemble the AE monitor including two representative sensors mounted on a calibration block with the same acoustic coupling process to be used for monitoring. The sensors shall be excited ten times by each of the following three methods:

(1) Fracture a 0.3 mm, 2H pencil lead against the surface of the block in accordance with SE-976.

(2) Strike the surface of the block with 0.25 in. (6 mm) diameter steel ball dropped from a uniform height sufficient to produce a response from the sensors that does not saturate the AE monitor.

(3) Inject a multi-cycle (five cycles minimum) burst signal into the block with a transducer and waveform generator.

(b) The pattern recognition function shall identify at least 8 out of 10 lead fracture signals as AE crack growth signals and at least 8 out of 10 of each other type signals as signals not associated with crack growth.

T-1344 Material Attenuation/Characterization

Prior to installation of AE system for monitoring plant components, the acoustic signal attenuation in the material shall be characterized. This is necessary for

determining the sensor spacing for effective AE detection. Attenuation measurements shall be made at the frequency selected for AE monitoring and shall include both surface and bulk wave propagation. The attenuation measurements should be performed with the material temperature within $\pm 200^{\circ}\text{F}$ ($\pm 111^{\circ}\text{C}$) of the expected temperature during actual component monitoring.

T-1345 Background Noise

The AE system response to background noise shall be characterized. With 90 dB amplification, the AE system signal level response to continuous process background noise shall not exceed $1.5 V_{\text{peak}}$ output. This shall be achieved by restricting the frequency response of the sensor system. Reducing sensitivity is not acceptable.

T-1346 Qualification Records

Documentation of the equipment qualification process shall include the following:

- (a) a copy of the equipment qualification procedure
- (b) personnel certificate records
- (c) description of the AE equipment and qualification equipment used
- (d) quantitative results of the qualification
- (e) signature of the AE Level III responsible for the qualification
- (f) date of the qualification

Equipment qualification records shall be retained as part of the monitoring application records.

T-1347 Sensor Installation

T-1347.1 Coupling. Adequate acoustic coupling between the sensor and the component surface shall be verified as the sensors are mounted. This can be done by lightly tapping the surface or by breaking a pencil lead against the component surface while observing the sensor output. Guidance for sensor mounting is provided in SE-650 and in T-1332.3. The use of drilled and tapped holes in the component is generally not acceptable.

T-1347.2 Array Spacing. A sufficient number of sensors shall be located on the component in a multi-source array(s) to provide for AE signal detection and source location. Each sensor shall produce an output of at least $0.3 \text{ mV}_{\text{peak}}$ when a 0.3 mm, 2H pencil lead is broken against the bare surface of the component at the most remote location that the sensor is expected to monitor. When a location algorithm is used, the

location of each lead break shall be surrounded with a material (mastic or putty) to absorb surface waves. A 0.1 in. (2.5 mm) lead extension shall be broken at an angle of approximately 30 deg. to the component surface.

T-1347.3 Functional Verification. One or more acoustic signal sources, with an output frequency range of 100 to 700 kHz shall be installed within the monitoring zone of each sensor array for the purpose of periodically testing the functional integrity of the sensors during monitoring. This is not intended to provide a precise sensor calibration but rather a qualitative sensitivity check. It shall be possible to activate the acoustic signal source(s) from the AE monitor location.

T-1348 Signal Lead Installation

The coaxial cable and other leads used to connect the sensors to the AE monitor shall be demonstrated to be capable of withstanding extended exposure to hostile environments as required to perform the monitoring activities.

T-1349 AE Monitor Installation

The AE monitor shall be located in a clean, controlled environment suitable for long-term operation of a computer system. The electronic instrumentation (preamplifiers and AE monitor components) shall be located in an area that is maintained at temperatures not exceeding 125°F .

T-1350 PROCEDURE REQUIREMENTS

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AE monitoring activities shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable:

- (a) Components to be monitored include dimension, materials of construction, operating environment, and duration of monitoring
- (b) a description of the AE system to be used and its capabilities in terms of the functional requirements for the intended application
- (c) AE system calibration and qualification requirements
- (d) number, location, and mounting requirements for AE sensors
- (e) interval and acceptable performance during the AE system functional check (T-1373.2)
- (f) data recording processes and data to be recorded

(g) data analysis, interpretation, and evaluation criteria

(h) supplemental NDE requirements

(i) personnel qualification/certification requirements

(j) reporting and record retention requirements

The procedure described below need not be large documents, and preprinted blank forms (technique sheets) may be utilized provided they contain the required information.

T-1351 AE System Operation

A written procedure describing operation of the AE system shall be prepared, approved by the cognizant AE Level III, and made available to the personnel responsible for operating the AE system. Each procedure shall be tailored to recognize and accommodate unique requirements associated with the plant system or component being monitored.

T-1352 Data Processing, Interpretation, and Evaluation

A written procedure for processing, interpreting, and evaluating the AE data shall be prepared and approved by the cognizant AE Level III. This procedure shall be made available to the personnel responsible for operating the AE system, the personnel responsible for AE data interpretation and evaluation, and a representative of the owner of the plant system being monitored. This procedure shall be tailored to recognize and accommodate unique requirements associated with the plant system or component being monitored.

T-1353 Data Recording and Storage

Specific requirements for recording, retention, and storage of the AE and other pertinent data shall be prepared for approval by representatives of the plant system owner or operator. These requirements shall be made available to the personnel responsible for data recording and storage.

T-1360 CALIBRATION

T-1361 Sensors

The frequency response for each AE channel shall be measured with the sensors installed on a plant pressure boundary component. Sensor response shall be measured at the output of the preamplifier using a spectrum analyzer. The excitation source shall be a

helium gas jet directed onto the component surface from a nominal 30 psi (207 kPa) source through a #18 hypodermic needle held perpendicular to the component surface at a stand-off distance of $\frac{1}{8}$ in. (3.2 mm) located $1\frac{1}{2}$ in. (38 mm) from the mounted sensor. The gas shall not impinge on the sensor or the waveguide. AE sensor peak response to the gas jet excitation at the monitoring frequency shall be at least 0.1 mV_{peak} referred to the output of the sensor. Any AE sensor showing less than 0.1 mV_{peak} output shall be reinstalled or replaced, as necessary, to achieve the required sensitivity.

An optional technique for determining the reproducibility of AE sensor response is referred to as the "Pencil Lead Break" technique which is described in SE-976.

T-1362 Complete AE Monitor System

T-1362.1 Detection and Source Location. The signal detection and source location accuracy for each sensor array shall be measured using simulated AE signals injected on the component surface at not less than 10 preselected points within the array monitoring field. These simulated AE signals shall be generated by breaking 2H pencil leads (0.3 or 0.5 mm diameter) against the component surface at the prescribed points. The pencil leads shall be broken at an angle of approximately 30 deg. to the surface using a 0.1 in. (2.5 mm) pencil lead extension (see SE-976). The location of each pencil lead break shall be surrounded with a material (mastic or putty) to absorb surface waves. Location accuracies within one wall thickness at the AE source location or 5% of the minimum sensor array spacing distance, whichever is greater, are typical.

T-1362.2 Function Verification. Response of the AE system to the acoustic signal source described in T-1347.3 shall be measured and recorded for reference during later checks of the AE system.

T-1363 Calibration Intervals

The installed AE monitor system shall be recalibrated in accordance with T-1360 at the end of each plant operating cycle. This is defined more explicitly in the Appendices describing requirements for each AE monitoring application.

T-1364 Calibration Records

Documentation of the installed system calibration shall include the following:

- (a) a copy of the calibration procedure(s)
- (b) personnel certification records
- (c) description of the AE equipment and the calibration equipment used
- (d) quantitative results of the calibration
- (e) signature of the individual responsible for the calibration

(f) date(s) of the calibration(s).

Retention of the calibration records shall be in accordance with T-1393.

T-1370 EXAMINATION

The AE monitor system shall comply with the requirements of approved procedures (T-1350) that have been accepted by the plant owner/operator.

T-1371 Personnel

Operation of the AE system for routine collection and interpretation of data may be performed by a competent individual not necessarily specialized in AE who has received training and has at least limited AE Level II certification. However, AE system operation and data interpretation shall be verified by a certified AE Level III on a monthly interval or sooner if the system appears to be malfunctioning or there is an abrupt change in the rate of AE data accumulation.

T-1372 Plant Startup

During plant startup, AE rate and source location information shall be evaluated at least once per shift for indications of flaw growth. The RMS signal level shall also be evaluated for indications of pressure boundary leaks.

T-1373 Plant Steady-State Operation

T-1373.1 Data Evaluation Interval

AE data shall be evaluated at least weekly during normal plant operation. When a sustained AE activity rate from one or more sensors occurs or when a consistent clustering of AE signals accepted by the signal identification analyzer and which cluster in one source location of AE signals is concentrated within a diameter of three times the wall thickness of the component or 10% of the minimum sensor spacing distance in the array, whichever is greater. Also refer to Appendices II and III.

T-1373.2 AE System Functional Check. AE system response to the installed acoustic signal source shall be evaluated periodically as specified in the procedure. Deterioration of sensitivity exceeding 4 dB for any channel shall be recorded and the affected component shall be replaced at the earliest opportunity.

T-1374 Nuclear Components

Specific and supplemental examination requirements for nuclear components are specified in Appendix I.

T-1375 Non-Nuclear Metal Components

Specific and supplemental examination requirements for non-nuclear metal components are specified in Appendix II.

T-1376 Non-Metallic Components

Specific and supplemental examination for non-metallic components are specified in Appendix III.

T-1377 Limited Zone Monitoring

Specific and supplemental examination requirements for limited zone monitoring are specified in Appendix IV.

T-1378 Hostile Environment Applications

Specific and supplemental examination requirements for hostile environment applications are specified in Appendix V.

T-1379 Leak Detection Applications

Specific and supplemental examination requirements for leak detection applications are specified in Appendix VI.

T-1380 EVALUATION/RESULTS

T-1381 Data Processing, Interpretation, and Evaluation

Data processing, interpretation, and evaluation shall be in accordance with the written procedure (T-1350) for that specific application and the applicable Mandatory Appendices. The methodology and criteria will vary substantially with different applications.

T-1382 Data Requirements

The following data shall be acquired and recorded:

(a) AE event count versus time for each monitoring array.

(b) AE source and/or zone location for all acoustic signals accepted.

(c) AE hit rate for each AE source location cluster.

(d) Relevant AE signal parameter(s) versus time for each data channel.

(e) Location monitored, date, and time period of monitoring.

(f) Identification of personnel performing the analysis.

In addition, the data records shall include any other information required in the applicable procedure (T-1350).

T-1390 REPORTS/RECORDS**T-1391 Reports to Plant System Owner/Operator**

T-1391.1 A summary of AE monitoring results shall be prepared monthly. This should be a brief, concise report for management use.

T-1391.2 Reporting requirements in the event of unusual AE indications shall be specified by the plant system owner/operator and identified in the procedure (T-1350).

T-1391.3 A summary report on the correlation of monitoring data with the evaluation criteria shall be provided to the plant system owner/operator.

T-1391.4 Upon completion of each major phase of the monitoring effort, a comprehensive report shall be prepared. This report shall include the following:

(a) complete identification of the plant system/component being monitored including material type(s), method(s) of fabrication, manufacturer's name(s), and certificate number(s)

(b) sketch or manufacturer's drawing with component dimensions and sensor locations

(c) plant system operating conditions including pressurizing fluid, temperature, pressure level, etc.

(d) AE monitoring environment including temperature, radiation and corrosive fumes if appropriate, sensor accessibility, background noise level, and protective barrier penetrations utilized, if any

(e) a sketch or manufacturer's drawing showing the location of any zone in which the AE response exceeded the evaluation criteria

(f) any unusual events or observations during monitoring

(g) monitoring schedule including identification of any AE system downtime during this time period

(h) names and qualifications of the AE equipment operators

(i) complete description of the AE instrumentation including manufacturer's name, model number, sensor types, instrument settings, calibration data, etc.

T-1392 Records

T-1392.1 Administrative Records. The administrative records for each AE monitoring application shall include the applicable test plan(s), procedure(s), operating instructions, evaluation criteria, and other relevant information, as applicable.

T-1392.2 Equipment Qualification and Calibration Data. The pre-installation and post-installation AE system qualification and calibration records including signal attenuation data and AE system performance verification checks shall be retained. Disposition of these records following AE system recalibration shall be specified by the plant system owner/operator.

T-1392.3 Raw and Processed AE Data. The raw data records shall be retained at least until the AE indications have been independently verified. The retention period for the processed data records shall be as specified in the procedure (T-1350).

T-1393 Record Retention Requirements

All AE records shall be maintained as required by the referencing Code section and the procedure (T-1350).

ARTICLE 13

MANDATORY APPENDICES

APPENDIX I — NUCLEAR COMPONENTS

I-1310 SCOPE

This Appendix specifies supplemental requirements for continuous AE monitoring of metallic components in nuclear plant systems. The requirements of Appendix V — Hostile Environment Applications shall also apply to continuous AE monitoring of nuclear plant systems.

I-1320 TERMS SPECIFIC TO THIS APPENDIX

See Appendix VII for definitions of terms specific to this Appendix.

I-1330 EQUIPMENT QUALIFICATION

I-1331 Preamplifiers

The internal electronic noise of the preamplifiers shall not exceed 7 microvolts rms referred to the input with a 50-ohm input termination. The frequency response band of the amplitude shall be matched to the response profile determined for the AE sensors.

I-1332 Monitor System

Acceptable performance, including dynamic range, of the complete AE monitor (without sensors) shall be verified using an electronic waveform generator prior to installation. Sinusoidal burst signals from the waveform generator shall be input to each preamplifier to verify that the signal amplification; data processing functions; data processing rate; and data analysis, display, and storage meet the requirements of this Article. (NOTE: AE signal source location performance is tested under T-1362.1.) The system shall be evaluated using input signals of 0.5 and 10.0 mV peak-to-peak amplitude; 0.5 and 3.0 millisecond duration; and 100 kHz, and 1.0 MHz frequency from the waveform generator.

I-1340 SENSORS

I-1341 Sensor Type

The AE sensors shall be capable of withstanding the ambient service environment (i.e., temperature, moisture, vibration, and nuclear radiation) for a period of two years. Refer to T-1332 and Appendix V, para. V-1320, for additional sensor requirements. In monitoring nuclear components, in addition to high temperature [$\approx 600^{\circ}\text{F}$ (316°C) in most locations], the environment at the surface of the component may also include gamma and neutron radiation. In view of the neutron radiation, a waveguide high temperature AE sensor such as the type described in Appendix V should be used to isolate the critical elements of the sensor (piezoelectric crystal and associated preamplifier) from the neutron radiation field.

I-1342 Frequency Response

The frequency response band of the sensor/amplifier combination shall be limited to avoid interference from background noise such as is caused by coolant flow. Background noise at the locations to be monitored shall be characterized in terms of intensity versus frequency prior to selection of the AE sensors to be used. This information shall be used to select the appropriate frequency bandwidth for AE monitoring. The sensor response roll off below the selected monitoring frequency shall be at a minimum rate of 15 dB per 100 kHz, and may be achieved by inductive tuning of the sensor/preamplifier combination. The high end of the frequency response band should roll off above 1 MHz at a minimum rate of 15 dB per octave to help reduce amplifier noise. These measurements shall be made using the helium gas jet technique described in T-1342.1 and T-1361.

I-1343 Signal Processing

The threshold for all sensor channels shall be set at 0.5 to 1.0 V_{peak} above the sensor channel background noise level and all channels shall be set the same.

I-1350 CALIBRATION**I-1351 Calibration Block**

The calibration block used to qualify AE sensors shall be a steel block with minimum dimensions of 4 × 12 × 12 in. (101.6 × 304.8 × 304.8 mm) with the sensor mounted in the center of a major face using the acoustic coupling technique to be applied during in-service monitoring.

I-1352 Calibration Interval

The installed AE monitor system shall be recalibrated in accordance with T-1360 during each refueling or maintenance outage, but no oftener than once every 24 months.

I-1360 EVALUATION/RESULTS

(a) The monitoring procedure (T-1350) shall specify the acceptance criteria for crack growth rate.

(b) The AE data shall be evaluated based on AE rate derived from signals accepted by the signal identification function and identified with a specific area of the pressure boundary.

(c) The data shall be analyzed to identify an increasing AE rate that is indicative of accelerating crack growth.

(d) The quantitative crack growth rate shall be estimated using the relationship:

$$\frac{da}{dt} = 290 \left(\frac{dN}{dt} \right)^{0.53}$$

where

da/dt = crack growth rate in microinches/second

dN/dt = the AE rate [AE as defined in (b) above] in events/second

(e) If the estimated crack growth rate exceeds the acceptance criteria, the flaw area shall be examined with other NDE methods at the earliest opportunity.

APPENDIX II — NON-NUCLEAR METAL COMPONENTS

II-1310 SCOPE

This Appendix specifies supplemental requirements for continuous AE monitoring of non-nuclear metal components. The principal objective is to monitor/detect acoustic emission (AE) sources caused by surface and

internal discontinuities in a vessel wall, welds, and fabricated parts and components.

II-1320 EQUIPMENT/QUALIFICATIONS**II-1321 Sensor Response**

Acoustic emission sensors shall have a resonant response between 100 kHz to 400 kHz. Minimum sensitivity shall be −85 dB referred to 1 volt/microbar determined by a face-to-face ultrasonic test. Sensors shall have a frequency response with variations not exceeding 4 dB from the peak response. Acoustic emission sensors in a face-to-face ultrasonic test (or equivalent) shall not vary in peak sensitivity by more than 3 dB from when they were new.

II-1322 Couplant

Couplant shall provide consistent coupling efficiency for the duration of the test.

II-1323 Preamplifier

The preamplifier shall be located within 6 ft (1.8 m) from the sensor, and differential preamplifiers shall have 40 dB of common-mode noise rejection. Frequency response shall not vary more than 3 dB over the operating frequency range of the sensors when attached. Filters shall be of the band pass or high pass type and shall provide a minimum of 24 dB of common-mode rejection.

II-1324 Signal Cable

Power signal cable shall be shielded against electromagnetic noise. Signal loss shall be less than 1 dB per foot of cable length. Recommended maximum cable length is 500 ft (152 m).

II-1325 Power Supply

A stable, grounded electrical power supply should be used.

II-1326 Main Amplifier

The main amplifier gain shall be within 3 dB over the range of 40°F to 125°F (4°C to 52°C).

II-1327 Main Processor

The main processor(s) shall have circuits for processing sensor data. The main processor circuits shall be capable of processing hits, counts, peak amplitudes, and MARSE on each channel, and measure the following:

(a) *Threshold.* The AE instrument shall have a threshold control accurate to within ± 1 dB over its useful range.

(b) *Counts.* The AE counter circuit shall detect counts over a set threshold with an accuracy of $\pm 5\%$.

(c) *Hits.* The AE instrument shall be capable of measuring, recording, and displaying a minimum of 20 hits/sec total for all channels.

(d) *Peak Amplitude.* The AE circuit shall measure peak amplitude with an accuracy of ± 2 dB. Useable dynamic range shall be a minimum of 60 dB with 1 dB resolution over the frequency bandwidth used. Not more than 2 dB variation in peak detection accuracy shall be allowed over the stated temperature range. Amplitude values shall be specified in dB and must be referenced to a fixed gain output of the system (sensor or preamplifier).

(e) *Energy.* The AE circuit shall measure MARSE with an accuracy of $\pm 5\%$. The useable dynamic range for energy shall be a minimum of 40 dB.

(f) *Parametric Voltage.* If parametric voltage is measured, it shall be measured to an accuracy of $\pm 2\%$ of full scale.

II-1330 SENSORS**II-1331 Sensor Mounting/Spacing**

Sensor location and spacing shall be based on attenuation characterization, with the test fluid in the vessel, and a simulated source of AE. Section V, Article 12, Nonmandatory Appendices should be referenced for vessel sensor placement. Consideration should be given to the possible attenuation effects of welds.

II-1332 Sensor Spacing for Multichannel Source Location

Sensors shall be located such that a lead break at any location within the examination area is detectable by at least the minimum number of sensors required for the multichannel source location algorithm, with the measured amplitude specified by the referencing Code Section. Location accuracy shall be within a maximum of 2 wall thicknesses or 5% of the sensor spacing distance, whichever is greater.

II-1333 Sensor Spacing for Zone Location

When zone location is used, sensors shall be located such that a lead break at any location within the examination area is detectable by at least one sensor with a measured amplitude not less than specified by the referencing Code Section. The maximum sensor spacing shall be no greater than one-half the threshold distance. The threshold distance is defined as the distance from a sensor at which a pencil-lead break on the vessel produces a measured amplitude equal to the evaluation threshold.

II-1340 CALIBRATION**II-1341 Manufacturer's Calibration**

Purchased AE system components shall be accompanied by manufacturer's certification of performance specifications and tolerances.

II-1342 Annual Calibration

The instrumentation shall have an annual, comprehensive calibration following the guideline provided by the manufacturer using calibration instrumentation meeting the requirements of a recognized national standard.

II-1343 System Performance Check

Prior to beginning the monitoring period, the AE instrument shall be checked by inserting a simulated AE signal at each main amplifier input. The device generating the simulated signal shall input a sinusoidal burst-type signal of measurable amplitude, duration, and carrier frequency. On-site system calibration shall verify system operation for threshold, counts, MARSE, and peak amplitude. Calibration values shall be within the range of values specified in II-1327.

II-1344 System Performance Check Verification

Verification of sensor coupling and circuit continuity shall be performed following sensor mounting and system hookup and again following the test. The peak amplitude response of each sensor to a repeatable simulated AE source at a specific distance from the sensor should be taken prior to and following the monitoring period. The measured peak amplitude should not vary more than ± 4 dB from the average of all the sensors. Any channel failing this check should be

TABLE II-1351
AN EXAMPLE OF EVALUATION CRITERIA FOR ZONE
LOCATION

	Pressure Vessels (Other Than First Hydrostatic Test) Using Zone Location
Emissions during hold	Not more than E hits beyond time T
Count rate	Less than N counts per sensor for a specified load increase
Number of hits	Not more than E hits above a specified amplitude
Large amplitude	Not more than E hits above a specified amplitude
MARSE or amplitude	MARSE or amplitudes do not increase with increasing load
Activity	Activity does not increase with increasing load
Evaluation threshold, dB	50 dB

repaired or replaced, as necessary. The procedure will indicate the frequency of system performance checks.

II-1350 EVALUATION

II-1351 Evaluation Criteria — Zone Location

All data from all sensors shall be used for evaluating indications. The AE criteria shown in Table II-1351 provide one basis for assessing the significance of AE indications. These criteria are based on a specific set of AE monitoring conditions. The criteria used for each application shall be as specified in the referencing Code Section and the AE procedure (see T-1350).

II-1352 Evaluation Criteria — Multisource Location

All data from all sensors shall be used for evaluating indications. The AE criteria shown in Table II-1352 provide one basis for assessing the significance of AE indications. These criteria are based on a specific set of AE monitoring conditions. The criteria used for each application shall be as specified in the referencing Code Section and the AE procedure (see T-1350).

APPENDIX III — NON-METALLIC COMPONENTS

III-1310 SCOPE

This Appendix specifies supplemental requirements for continuous monitoring of non-metallic (fiber reinforced plastic) components.

III-1320 BACKGROUND

Non-metallic (FRP) components such as pressure vessels, storage tanks, and piping, are typically used at relatively low temperature. Due to high attenuation and anisotropy of the material, AE methodology has proven to be more effective than other NDE methods.

III-1321 References

(a) *Pressure Vessels*. Section V, Article 11 — Acoustic Emission Examination of Fiberglass Tanks/Vessels

(b) *Atmospheric Tanks*. Section V, Article 11 — Acoustic Emission Examination of Fiberglass Vessels, ASNT/CARP Recommended Practice ASTM E 1067: Acoustic Emission Examination of Fiberglass Reinforced Plastic Resin Tanks/Vessels

(c) *Piping*. ASTM E 1118 — Standard Practice for Acoustic Emission Examination of Reinforced Thermosetting Resin Pipe (RTRP)

III-1330 MATERIAL CONSIDERATIONS

High attenuation and anisotropy of the material are controlling factors in sensor frequency, source location accuracy, and sensor spacing.

III-1331 Sensor Frequency

Sensors used for monitoring FRP equipment shall be resonant in the 20–200 kHz frequency range.

III-1332 Source Location Accuracy

III-1332.1 Exact solution source location techniques shall be used in monitoring FRP where high accuracy is required. For these applications special precautions will be taken to account for unpredictable acoustic velocity variations in the material. Sensor spacing shall be no greater than 20 in. (508 mm).

III-1332.2 Zone location techniques require the AE signal to hit only one sensor to provide useful location

data. Sensor spacing of 5 ft–20 ft (1.5 m–6.0 m) may be used to cover large areas or the entire vessel.

III-1340 CALIBRATION

III-1341

A manufacturer's calibration of the instrumentation should be conducted on an annual basis. Instrumentation used for calibration shall be referenced to NIST.

III-1342

Periodic field calibration shall be performed with an AE waveform generator to verify performance of the signal processor.

III-1343

Hsu-Nielsen lead break and/or gas jet performance verification techniques (T-1362.2) shall be performed periodically to check all components including couplant, sensor, signal processor, and display.

III-1344

Low amplitude threshold (LAT) shall be determined using the 4 ft by 6 ft by $\frac{1}{2}$ in. (1.2 m $\times$ 1.8 m $\times$ 13 mm) 99% pure lead sheet. The sheet shall be suspended clear of the floor. The LAT threshold is defined as the average measured amplitude of ten events generated by a 0.3 mm pencil (2H) lead break at a distance of 4 ft, 3 in. (1.3 m) from the sensor. All lead breaks shall be done at an angle of approximately 30 deg. to the surface with a 0.1 in. (2.5 mm) lead extension. The sensor shall be mounted 6 in. (152 mm) from the 4 ft (1.2 m) side and mid-distance between 6 ft (1.8 m) sides.

III-1345

High amplitude threshold (HAT) shall be determined using a 10 ft by 2 in. by 12 in. (3.0 m $\times$ 51 mm $\times$ 305 mm) clean, mild steel bar. The bar shall be supported at each end on elastomeric or similar isolating pads. The HAT threshold is defined as the average measured amplitude of ten events generated by a 0.3 mm pencil (2H) lead break at a distance of 7 ft (2.1 m) from the sensor. All lead breaks shall be done at an angle of approximately 30 deg. to the surface with a 0.1 in. (2.5 mm) extension. The sensor shall be mounted 12 in. (305 mm) from the end of the bar on the 2 in. (51 mm) wide surface.

III-1350 EVALUATION/RESULTS

III-1351 Evaluation Criteria

The monitoring procedure (T-1350) shall specify the acceptance criteria.

III-1351.1 AE activity above defined levels indicates that damage is occurring.

III-1351.2 Felicity ratio from subsequent loadings to a defined level can indicate the amount of previous damage.

III-1351.3 Emission activity during periods of contact load indicates that damage is occurring at an accelerating rate.

III-1352 Source Mechanism

III-1352.1 Matrix cracking, fiber debonding, and matrix crazing are characterized by numerous low amplitude acoustic emission signals. Matrix cracking and fiber debonding are generally the first indications of failure. Matrix crazing is normally an indication of corrosion or excessive thermal stress.

III-1352.2 Delamination is characterized by high signal strength, medium amplitude AE activity. This type of failure is typically found at joints with secondary bonds.

III-1352.4 High amplitude AE activity (over High Amplitude Threshold) is associated with fiber breakage and is an indication of significant structural damage.

APPENDIX IV — LIMITED ZONE MONITORING

IV-1310 SCOPE

This Appendix specifies supplemental requirements for applications involving limited zone monitoring, where one of the objectives is to consciously limit the area or volume of the component or pressure boundary that is monitored by AE. Typical reasons for limiting the monitored area include: (a) observe the behavior of a known flaw at a specific location; (b) restrict the AE response to signals emanating from specific areas or volumes of the pressure boundary (e.g., restrict the area monitored by AE to one or more nozzle-to-vessel welds, monitor specific structural welds, etc.); (c) restrict the AE examination to areas of known susceptibility to failure due to fatigue, corrosion, etc.; or (d) improve the signal-to-noise ratio.

TABLE II-1352
AN EXAMPLE OF EVALUATION CRITERIA FOR
MULTISOURCE LOCATION

	Pressure Vessels (Other Than First Hydrostatic Test) Using Multisource Location
Emissions during hold	Not more than E hits from a cluster beyond time T
Count rate	Less than N counts from a cluster for a specified load increase
Number of hits	Not more than E hits from a cluster above a specified amplitude
Large amplitude	Not more than E hits from a cluster above a specified amplitude
Marse or aplitude	MARSE or amplitudes from a cluster do not increase with increasing load
Activity	Activity from a cluster does not increase with increasing load
Evaluation threshold, dB	50 dB or specified in procedure

IV-1320 TERMS SPECIFIC TO THIS APPENDIX

See Appendix VII for definitions of terms specific to this Appendix.

IV-1330 GENERAL

IV-1331 Techniques

Limited zone monitoring is accomplished by installing sensors in or around the area of interest. Signals originating from outside the area of interest are excluded from the analysis using techniques such as triangulation, amplitude discrimination, coincidence detection, or signal arrival sequence.

IV-1332 Guard Sensor Technique

One common signal arrival sequence technique uses guard sensors to limit the area of interest. The guard sensor technique involves placing additional sensors further outside the area of interest than the detection sensors. Signals arriving at a guard sensor before any of the detection sensors are rejected. Signals originating from within the area of interest arrive at a detection sensor before any of the guard sensors and are accepted by the data acquisition and analysis process.

IV-1333 Other Techniques

The preceding descriptions of typical limited zone monitoring techniques shall not preclude the use of other techniques to provide this function.

IV-1340 REQUIREMENTS

IV-1341 Procedure

When limited zone monitoring is intended, the technique used to accomplish this function shall be described in the procedure (T-1350). Any technique, or combination of techniques, may be utilized to accomplish limited zone monitoring provided the technique(s) is described in the applicable procedure.

IV-1342 Redundant Sensors

Where appropriate, redundant sensors should be used to provide additional assurance that the failure of a single sensor will not preclude continued operation of the AE system throughout the specified monitoring period.

IV-1343 System Calibration

During the system calibration performed in accordance with T-1362, the effectiveness of the limited zone monitoring technique(s) shall be demonstrated by introducing artificial AE signals both inside and outside the area of interest. The AE system shall accept at least 90% of the signals that originate inside the area of interest, and reject at least 90% of the signals that originate outside the area of interest. Such signal discrimination may be accomplished using any of the techniques listed above as specified in the procedure (T-1350).

IV-1350 EVALUATION/RESULTS

Data processing and interpretation shall be performed consistent with the objectives of limited zone monitoring. Precautions shall be taken to confirm that signals originating from inside the area of interest are not confused with signals originating from outside the area of interest. Care shall also be taken to check that the system's ability to monitor the area of interest was not compromised by excessive noise from outside the area of interest.

IV-1360 REPORTS/RECORDS

All reports of data acquired using the limited zone monitoring approach shall clearly and accurately identify the effective area of interest.

APPENDIX V — HOSTILE ENVIRONMENT APPLICATIONS**V-1310 SCOPE**

This Appendix specifies supplemental requirements for continuous AE monitoring of pressure containing components during operation at high temperatures and in other hostile environments. As used herein, high temperature means as any application where the surface to be monitored will exceed 300°F (149°C), which is the nominal upper temperature limit for most general purpose AE sensors. Other hostile environments include corrosive environments, high vapor atmospheres, nuclear radiation, etc.

V-1320 SENSORS

For high temperature applications, special high temperature sensors shall be used. There are two basic types of sensors for such applications. Surface mounted sensors constructed to withstand high temperatures and waveguide sensors which remove the sensor's piezoelectric sensor from the high temperature environment through the use of a connecting waveguide. A thin, soft metal, interface layer between the sensor and the component surface has proven effective for reducing the interface pressure required to achieve adequate acoustic coupling.

V-1321 Surface Mounted Sensors

Sensors to be mounted directly on the surface shall be evaluated for their capability to withstand the environment for the duration of the planned monitoring period. Some sensors rated for high temperature service are limited in the time for which they can survive continuous exposure at their rated temperature.

V-1322 Waveguide Sensors

The waveguide sensors described below are suitable for hostile environment applications where the sensor unit (piezoelectric crystal and 20 dB preamplifier) can be placed in a less hostile environment [e.g., lower temperature of about 200°F (93°C)] through the use

of a waveguide no more than 20 ft (6.1 m) long. The length of the waveguide is not an absolute; however, as the waveguide length increases, the signal attenuation in the waveguide also increases.

Waveguide sensors are a special type of sensor used for hostile environments. A type of waveguide sensor that has been used effectively to monitor components with surface temperatures to 1800°F (982°C) is shown in Fig. V-1322. A waveguide 20 ft (6.1 m) long was used to move the sensor unit (piezoelectric crystal and 20 dB preamplifier) away from the high temperature to an environment of about 200°F (93°C). The sensor was still exposed to a nuclear radiation environment of about 45,000 Rad/hr gross gamma. When monitoring was completed after 120 days, the sensors were still operating with no evidence of deterioration. These sensor types have been used in various applications with waveguide lengths ranging from 2 to 20 ft (0.6 m to 6.1 m) for periods up to 2½ years, and the attenuation in a 0.130 in. (3.30 mm) diameter Type 308 stainless steel waveguide has been measured to be 0.45 dB/ft.

V-1323 Sensor Monitoring

Refer to T-1332.3 for a discussion of sensor mounting. Most extreme temperature applications require mechanical mounting with pressure coupling of the sensors due to the temperature limitations of glues or epoxies. A sensor mounting fixture held in place by stainless steel bands or magnets has proven to be effective; however, if magnets are used, the ability of the magnet to retain its magnetic properties in the temperature environment must be evaluated. The fixture shown in Fig. V-1323 has been successfully used in a variety of waveguide sensor applications.

This fixture design provides a constant load on the waveguide tip against the component surface through the use of a spring. It has been found through practice that an interface pressure of about 16,000 psi (110 MPa) is required for good acoustic coupling. For the waveguide sensor shown in Fig. V-1322 with a waveguide tip diameter of 0.05 in. (1.27 mm), 30 pounds (0.13 kN) force for the mounting fixture provides the required interface pressure.

V-1324 Signal Cables

Special coaxial cables rated for the expected temperature shall be used to conduct AE signal information from the AE sensor to a location outside of the environment. Refer also to T-1333 and T-1348.

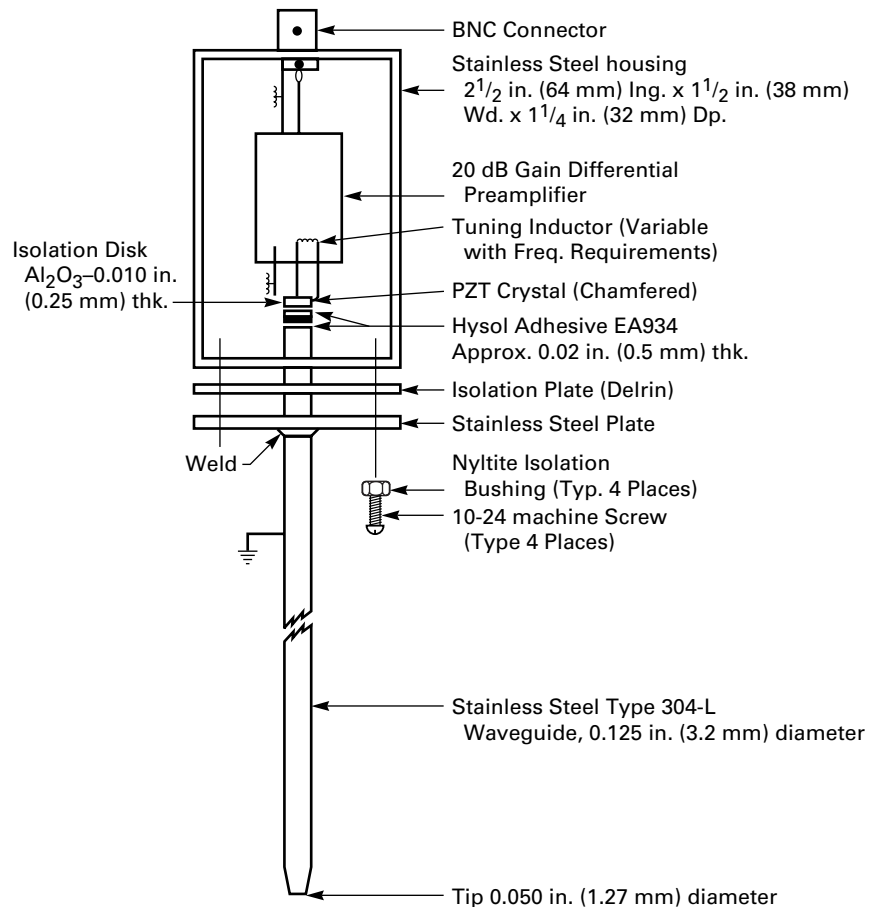


FIG. V-1322 METAL WAVEGUIDE AE SENSOR CONSTRUCTION

APPENDIX VI — LEAK DETECTION APPLICATIONS

VI-1310 SCOPE

This Appendix specifies supplemental requirements for continuous AE monitoring of metallic and non-metallic components to detect leaks from the pressure boundary. The objective in examining the pressure boundary of systems and components is to assess the leak integrity and identify the leakage area. The requirements of Appendix I — Nuclear Components and Appendix V — Hostile Environment Applications may also be applicable. SE-1211 should be consulted as a general reference.

VI-1320 GENERAL

The desire to enhance leak detection capabilities has led to research to improve acoustic leak detection

technology including technology that is applicable to the pressure boundary of nuclear reactors. Several methods are available for detecting leaks in pressure boundary components including monitoring acoustic noise due to fluid flow at a leakage site. The advantages of acoustic monitoring are rapid response to the presence of a leak and the capability to acquire quantitative information about a leak. Acoustic leak detection methods may be used to detect gas, steam, water, and chemical leaks for both nuclear and non-nuclear applications.

VI-1330 EQUIPMENT

VI-1331 Sensor Type

AE sensors with known sensitivity in the frequency range 200 kHz to 500 kHz shall be used in the presence of high background noise. For components in the

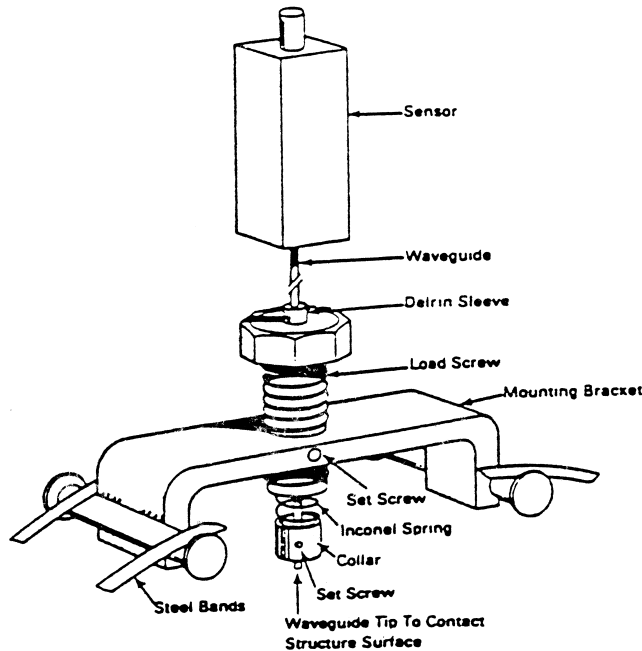


FIG. V-1323 MOUNTING FIXTURE FOR STEEL WAVEGUIDE AE SENSOR

presence of low background noise, monitoring shall be carried out at lower frequencies. Leak detection at frequencies below 100 kHz and as low as 1 kHz may be necessary for leak detection with non-metallic components.

VI-1331.1 Sensor selection shall be based on consideration of the following:

- (a) center frequency
- (b) bandwidth
- (c) ruggedness
- (d) response to temperature
- (e) humidity
- (f) ability of cables and preamplifiers to withstand the specific environment.

Using a simulation, sensor response characteristics and curves of leak rate vs. acoustic signal intensity shall be determined before installation to maximize the utility of the information in the acoustic signal.

VI-1331.2 Sensors not specified in this Appendix may be used if they have been shown to be appropriate for the application and meet the requirements of this Article. Alternate sensors, such as accelerometers, microphones, and hydrophones shall be included.

VI-1332 Waveguide

Waveguides may be used to isolate the sensor from hostile environments such as high temperatures or nuclear radiation for nuclear reactor applications.

VI-1332.1 Waveguide installations shall consider the following waveguide parameters:

- (a) length
- (b) diameter
- (c) surface finish
- (d) material of construction (i.e., ferritic steel, stainless steel, aluminum, and ceramic materials)

Waveguides having 3 mm to 13 mm in diameter and up to 250 mm in length have been shown to be effective and shall be used.

VI-1332.2 Coupling. Appendix V, para. V-1323 describes one method for mounting the waveguide. Others that have been shown effective are:

- (a) weld the waveguide to the pressure boundary
- (b) screw the waveguide into a plate attached to the order to mechanically press the waveguide against the metal component
- (c) screw the waveguide directly into the pressure boundary component
- (d) attach the sensor directly to the component.

Either gold foil or rounded waveguide tips have been shown to be effective when mechanically coupling the waveguide to the pressure boundary component. Occasionally, sensors are mounted and passed through the pressure boundary of a component in order to have the sensor in the process fluid. The sensor(s) shall then be capable of withstanding the ambient service environment of the process fluid. In addition, a safety analysis for installation and monitoring of the system shall be performed.

VI-1333 Electronic Filters

The response of the electronic filter(s) shall be adjustable to achieve the selected monitoring frequency range of operation as needed (see Appendix I). Frequency bandwidths in the range of 200–250 kHz should be available for high background noise environments and 1–200 kHz for low background noise environments.

VI-1340 CALIBRATION

VI-1341 Procedure

A calibration procedure shall be established and shall incorporate either the pencil-lead break and/or gas jet techniques described in T-1360 and Appendix I.

VI-1342 Calibration Checks

Sensor calibration checks may be conducted by electronically pulsing one of the sensors while detecting the associated acoustic wave with the other sensors.

VI-1350 EXAMINATION**VI-1351 Implementation of System Requirements**

In order to implement an acoustic leak detection and location system, the following preliminary steps shall be accomplished.

- (a) identify the acoustic receiver sites
- (b) determine the spacing between waveguides or sensors
- (c) meet the sensitivity needs for the system requirements
- (d) establish the level of background noise
- (e) estimate signal-to-noise ratios as a function of distance and level of background noise for acoustic signals in the frequency range selected.

VI-1352 Calibration Procedure

A calibration procedure shall be established. During the monitoring period, a self-checking system shall be performed to assure the system is functioning properly.

VI-1353 Equipment Qualification and Calibration Data

The acoustic equipment qualification and calibration data requirements shall be in accordance with T-1392.

VI-1360 EVALUATION/RESULTS**VI-1361 Leak Indications**

Detection of a leak or leakage indication near or at a sensor site will be indicated by an increase in the RMS signal over background noise. The signal increase shall be at least 3 dB or greater above background for a period of at least 30 min.

VI-1362 Leak Location

The general location of a leak can be established by the analysis of the relative amplitude of the RMS signals received by the sensor(s). Leak location may

also be determined by cross-correlation analysis of signals received at sensors, to either side of the leak site. When leakage location accuracy is desired, it may be necessary to spatially average the correlograms of the acoustic signals at each sensor site by installing an array of sensors. A minimum of three waveguides, separated by a minimum of 10 cm, is required for averaging of correlograms. This allows nine correlograms to be generated and averaged for each pair of sensor locations. Self-checking and calibration for the system shall be in accordance with VI-1340. If acoustic background levels are relatively constant, they may also be used to determine whether a probe is failing.

APPENDIX VII — GLOSSARY OF TERMS FOR ACOUSTIC EMISSION EXAMINATION

VII-1310 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms that appear in Article 13, Continuous Acoustic Emission Monitoring.

VII-1320 GENERAL REQUIREMENTS

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 provides the definitions of terms listed in VII-1330(a).

(c) For general terms, such as *Interpretation*, *Flaw*, *Discontinuity*, *Evaluation*, etc., refer to Article 1, Mandatory Appendix I.

(d) Paragraph VII-1330(b) provides a list of terms and definitions that are in addition to SE-1316 and are Code specific.

VII-1330 REQUIREMENTS

(a) All of the terms listed in SE-1316 are used in conjunction with this Article.

(b) The following Code terms are used in conjunction with this Article:

AE Monitor — all of the electronic instrumentation and equipment (except sensors and cables) used to detect, analyze, display, and record AE signals

Continuous Monitoring — the process of monitoring a pressure boundary continuously to detect acoustic emission during plant startup, operation, and shutdown

dB_{AE} — the peak voltage amplitude of the acoustic emission signal waveform expressed by the equation $dB_{AE} = 20 \log V/V_{Ref}$, where V_{Ref} is 1 μV out of the AE sensor crystal

Limited Zone Monitoring — the process of monitoring only a specifically defined portion of the pressure boundary by using either the sensor array configuration, controllable instrumentation parameters, or both to limit the area being monitored

Penetrations — In nuclear applications, the term penetrations refers to step-plugs containing electronic instrumentation cable sections installed through

shielding or containment walls to permit passing instrumentation power and information signals through these protective walls without compromising the protective integrity of the wall

Plant/Plant System — the complete pressure boundary system including appurtenances, accessories, and controls that constitute an operational entity

Plant Operation — normal operation including plant warmup, startup, shutdown, and any pressure or other stimuli induced to test the pressure boundary for purposes other than the stimulation of AE sources

Sensor Array — multiple AE sensors arranged in a geometrical configuration that is designed to provide AE source detection/location for a given plant component or pressure boundary area to be monitored

Subsection B

**Documents Adopted
by Section V**

SUBSECTION B

Article 22	Radiographic Standards.....	264
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ARTICLE 22

RADIOGRAPHIC STANDARDS

SE-94 (ASTM E 94-93)	Standard Guide for Radiographic Testing	265
SE-747 (ASTM E 747-97)	Standard Practice for Design, Manufacture, and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology.....	285
SE-999 (ASTM E 999-95)	Standard Guide for Controlling the Quality of Industrial Radiographic Film Processing.....	302
SE-1025 (ASTM E 1025-98)	Standard Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology	307
SE-1030 (ASTM E 1030-95)	Standard Test Method for Radiographic Examination of Metallic Castings.....	314
SE-1079 (ASTM E 1079-97)	Standard Practice for Calibration of Transmission Densitometers.....	326
SE-1114 [ASTM E 1114-92 (R1997)]	Standard Test Method for Determining the Focal Size of Iridium- 192 Industrial Radiographic Sources.....	328
SE-1165 [ASTM E 1165-92 (R1996)]	Standard Test Method for Measurement of Focal Spots of Industrial X-Ray Tubes by Pinhole Imaging.....	334
SE-1255 (ASTM E 1255-96)	Standard Practice for Radioscopy	342
SE-1416 (ASTM E 1416-96)	Standard Test Method for Radioscopic Examination of Weldments	359
SE-1647 (ASTM E 1647-98a)	Standard Practice for Determining Contrast Sensitivity in Radioscopy.....	365
SE-1815 (ASTM E 1815-96)	Standard Test Method for Classification of Film Systems for Industrial Radiography	370

STANDARD GUIDE FOR RADIOGRAPHIC TESTING



SE-94



(Identical with ASTM Specification E 94-93)

1. Scope

1.1 This guide covers satisfactory X-ray and gamma-ray radiographic testing as applied to industrial radiographic film recording. It includes statements about preferred practice without discussing the technical background which justifies the preference. A bibliography of several textbooks and standard documents of other societies is included for additional information on the subject.

1.2 This guide covers types of materials to be inspected; radiographic testing techniques and production methods; radiographic film section, processing, viewing, and storage; maintenance of inspection records; and a list of available reference radiograph documents.

NOTE 1 — Further information is contained in Guide E 999, Practice E 1025, Test Method E 1030, and Method E 1032.

1.3 Interpretation and Acceptance Standards — Interpretation and acceptance standards are not covered by this guide, beyond listing the available reference radiograph documents for casting and welds. Designation of accept-reject standards is recognized to be within the cognizance of product specifications and generally a matter of contractual agreement between producer and purchaser.

1.4 Safety Practices — Problems of personnel protection against X-rays and gamma rays are not covered by this document. For information on this important aspect of radiography, reference should be made to the current document of the National Committee on Radiation Protection and Measurement, Federal Register, U.S. Energy Research and Development Administration, National Bureau of Standards, and to state and local regulations, if such exist.

1.5 *This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish*

appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

1.6 If an NDT agency is used, the agency shall be qualified in accordance with Practice E 543.

2. Referenced Documents

2.1 ASTM Standards:

- E 142 Method for Controlling Quality of Radiographic Testing
- E 543 Practice for Evaluating Agencies that Perform Nondestructive Testing
- E 746 Test Method for Determining the Relative Image Quality Response of Industrial Radiographic Film
- E 747 Test Method for Controlling Quality of Radiographic Testing Using Wire Penetrators
- E 801 Practice for Controlling Quality of Radiographic Testing of Electronic Devices
- E 999 Guide for Controlling the Quality of Industrial Radiographic Film Processing
- E 1025 Practice for Hole-Type Image Quality Indicators Used for Radiography
- E 1030 Test Method for Radiographic Testing of Metallic Castings
- E 1032 Method for Radiographic Examination of Weldments
- E 1079 Practice for Calibration of Transmission Densitometers
- E 1254 Guide for Storage of Radiographs and Unexposed Industrial Radiographic Films
- E 1316 Terminology for Nondestructive Examinations

2.2 ANSI Standards:

- PH1.41 Specifications for Photographic Film for Archival Records, Silver-Gelatin Type, on Polyester Base
- PH2.22 Methods for Determining Safety Times of Photographic Darkroom Illumination

PH4.8 Methylene Blue Method for Measuring Thiosulfate and Silver Densitometric Method for Measuring Residual Chemicals in Films, Plates, and Papers

T9.1 Imaging Media (Film) — Silver-Gelatin Type Specifications for Stability

T9.2 Imaging Media — Photographic Processed Films, Plates, and Papers — Filing Enclosures and Storage Containers

3. Terminology

3.1 Definitions — For definitions of terms used in this guide, refer to Terminology E 1316.

4. Significance and Use

4.1 Within the present state of the radiographic art, this guide is generally applicable to available materials, processes, and techniques where industrial X-ray films are used as the recording media.

4.2 Limitations — This guide does not take into consideration special benefits and limitations resulting from the use of nonfilm recording media or readouts such as paper, tapes, xeroradiography, fluoroscopy, and electronic image intensification devices. Although reference is made to documents that may be used in the identification and grading, where applicable, of representative discontinuities in common metal castings and welds, no attempt has been made to set standards of acceptance for any material or production process. Radiography will be consistent in sensitivity and resolution only if the effect of all details of techniques, such as geometry, film, filtration, viewing, etc., is obtained and maintained.

PART I — EQUIPMENT AND PROCEDURE

5. Radiographic Quality Level

5.1 The quality level usually required for radiography is 2% (2-2T when using hole type IQI) unless a higher or lower quality is agreed upon between the purchaser and the supplier. At the 2% subject contrast level, three quality levels of inspection, levels 2-1T, 2-2T, and 2-4T, are available through the design and application of the IQI Practice E 1025, Table 1. The level of inspection specified should be based on the service requirements of the product. Great care should be taken in specifying quality levels 2-1T, 1-1T, and 1-2T by first determining that these quality levels can be maintained in production radiography.

NOTE 2 — The first number of the quality level designation refers to IQI thickness expressed as a percentage of specimen thickness; the second number refers to the diameter of the IQI hole that must be visible on the radiograph, expressed as a multiple of penetrameter thickness, T .

5.2 If IQIs of material radiographically similar to that being examined are not available, IQIs of the required dimensions but of a lower-absorption material may be used.

5.3 The quality level required using wire IQIs shall be equivalent to the 2-2T level of Practice E 1025 unless a higher or lower quality level is agreed upon between purchaser and supplier. Table 4 of Test Method E 747 gives a list of various hole-type IQIs and the diameter of the wires of corresponding EPS with the applicable 1T, 2T, and 4T holes in the plaque IQI. Appendix XI of Test Method E 747 gives the equation for calculating other equivalencies, if needed.

6. Energy Selection

6.1 X-ray energy affects image quality. In general, the lower the energy of the source utilized the higher the achievable radiographic contrast, however, other variables such as geometry and scatter conditions may override the potential advantage of higher contrast. For a particular energy, a range of thicknesses, which are a multiple of the half value layer, may be radiographed to an acceptable quality level utilizing a particular X-ray machine or gamma ray source. In all cases the specified IQI (penetrameter) quality level must be shown on the radiograph. In general, satisfactory results can normally be obtained for X-ray energies between 100 kV to 500 kV in a range between 2.5 to 10 half value layers (HVL) of material thickness (see Table 1). This range may be extended by as much as a factor of 2 in some situations for X-ray energies in the 1–25 MV range primarily because of reduced scatter.

7. Radiographic Equivalence Factors

7.1 The radiographic equivalence factor of a material is that factor by which the thickness of the material must be multiplied to give the thickness of a “standard” material (often steel) which has the same absorption. Radiographic equivalence factors of several of the more common metals are given in Table 2, with steel arbitrarily assigned a factor of 1.0. The factors may be used:

7.1.1 To determine the practical thickness limits for radiation sources for materials other than steel, and

TABLE 1
TYPICAL STEEL HVL THICKNESS IN INCHES (MM)
FOR COMMON ENERGIES

Energy	Thickness, in. (mm)
120 kV	0.10 (2.5)
150 kV	0.14 (3.6)
200 kV	0.20 (5.1)
250 kV	0.25 (6.4)
400 kV (Ir 192)	0.35 (8.9)
1 Mv	0.57 (14.5)
2 Mv (Co 60)	0.80 (20.3)
4 Mv	1.00 (25.4)
6 Mv	1.15 (29.2)
10 Mv	1.25 (31.8)
16 Mv and higher	1.30 (33.0)

TABLE 2
APPROXIMATE RADIOGRAPHIC EQUIVALENCE FACTORS FOR SEVERAL METALS
(RELATIVE TO STEEL)

Metal	Energy Level								¹⁹² Ir	⁶⁰ Co
	100 kV	150 kV	220 kV	250 kV	400 kV	1 MV	2 MV	4 to 25 MV		
Magnesium	0.05	0.05	0.08							
Aluminum	0.08	0.12	0.18						0.35	0.35
Aluminum alloys	0.10	0.14	0.18						0.35	0.35
Titanium		0.54	0.54		0.71	0.9	0.9	0.9	0.9	0.9
Iron/all steels	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Copper	1.5	1.6	1.4	1.4	1.4	1.1	1.1	1.2	1.1	1.1
Zinc		1.4	1.3		1.3			1.2	1.1	1.0
Brass		1.4	1.3		1.3	1.2	1.1	1.0	1.1	1.0
Inconel X		1.4	1.3		1.3	1.3	1.3	1.3	1.3	1.3
Monel	1.7		1.2							
Zirconium	2.4	2.3	2.0	1.7	1.5	1.0	1.0	1.0	1.2	1.0
Lead	14.0	14.0	12.0			5.0	2.5	2.7	4.0	2.3
Hafnium			14.0	12.0	9.0	3.0				
Uranium			20.0	16.0	12.0	4.0		3.9	12.6	3.4

7.1.2 To determine exposure factors for one metal from exposure techniques for other metals.

8. Film

8.1 Various industrial X-ray film types are available to meet the needs of production radiographic work. However, definite rules on the selection of film are difficult to formulate because the choice depends on individual user requirements. Some user requirements are as follows: radiographic quality levels, exposure times, and various cost factors. Several methods are available for assessing image quality levels (see Method E 142, Test Methods E 746 and E 747, and Practice E 801). Information about specific products can be obtained from the manufacturers.

9. Filters

9.1 Definition — Filters are uniform layers of material placed between the radiation source and the film.

9.2 Purpose — The purpose of filters is to absorb the softer components of the primary radiation, thus resulting in one or several of the following practical advantages:

9.2.1 Decreasing scattered radiation, thus increasing contrast.

9.2.2 Decreasing undercutting, thus increasing contrast.

9.2.3 Decreasing contrast of parts of varying thickness.

9.3 Location — Usually the filter will be placed in one of the following two locations:

9.3.1 As close as possible to the radiation source, which minimizes the size of the filter and also the contribution of the filter itself to scattered radiation to the film.

9.3.2 Between the specimen and the film in order to absorb preferentially the scattered radiation from the specimen. It should be noted that lead foil and other metallic screens (see 12.1) fulfill this function.

9.4 Thickness and Filter Material — The thickness and material of the filter will vary depending upon the following:

9.4.1 The material radiographed.

9.4.2 Thickness of the material radiographed.

9.4.3 Variation of thickness of the material radiographed.

9.4.4 Energy spectrum of the radiation used.

9.4.5 The improvement desired (increasing or decreasing contrast). Filter thickness and material can be calculated or determined empirically.

10. Masking

10.1 Masking or blocking (surrounding specimens or covering thin sections with an absorptive material) is helpful in reducing scattered radiation. Such a material can also be used to equalize the absorption of different sections, but the loss of detail may be high in the thinner sections.

11. Back-Scatter Protection

11.1 Effects of back-scattered radiation can be reduced by confining the radiation beam to the smallest practical cross section and by placing lead behind the film. In some cases either or both the back lead screen and the lead contained in the back of the cassette or film holder will furnish adequate protection against back-scattered radiation. In other instances, this must be supplemented by additional lead shielding behind the cassette or film holder.

11.2 If there is any question about the adequacy of protection from back-scattered radiation, a characteristic symbol [frequently a $\frac{1}{8}$ -in. (3.2-mm) thick letter B] should be attached to the back of the cassette or film holder, and a radiograph made in the normal manner. If the image of this symbol appears on the radiograph as a lighter density than background, it is an indication that protection against back-scattered radiation is insufficient and that additional precautions must be taken.

12. Screens

12.1 Metallic Foil Screens:

12.1.1 Lead foil screens are commonly used in direct contact with the films, and, depending upon their thickness, and composition of the specimen material, will exhibit and intensifying action at as low as 90 kV. In addition, any screen used in front of the film acts as a filter (Section 9) to preferentially absorb scattered radiation arising from the specimen, thus improving radiographic quality. The selection of lead screen thickness, or for that matter, any metallic screen

thickness, is subject to the same considerations as outlined in 9.4. Lead screens lessen the scatter reaching the film regardless of whether the screens permit a decrease or necessitate an increase in the radiographic exposure. To avoid image unsharpness due to screens, there should be intimate contact between the lead screen and the film during exposure.

12.1.2 Lead foil screens of appropriate thickness should be used whenever they improve radiographic quality or penetrometer sensitivity or both. The thickness of the front lead screens should be selected with care to avoid excessive filtration in the radiography of thin or light alloy materials, particularly at the lower kilovoltages. In general, there is no exposure advantage to the use of 0.005 in. in front and back lead screens below 125 kV in the radiography of $\frac{1}{4}$ -in. (6.35-mm) or lesser thickness steel. As the kilovoltage is increased to penetrate thicker sections of steel, however, there is a significant exposure advantage. In addition to intensifying action, the back lead screens are used as protection against back-scattered radiation (see Section 11) and their thickness is only important for this function. As exposure energy is increased to penetrate greater thicknesses of a given subject material, it is customary to increase lead screen thickness. For radiography using radioactive sources, the minimum thickness of the front lead screen should be 0.005 in. (0.13 mm) for iridium-192, and 0.010 in. (0.25 mm) for cobalt-60.

12.2 Other Metallic Screen Materials:

12.2.1 Lead oxide screens perform in a similar manner to lead foil screens except that their equivalence in lead foil thickness approximates 0.0005 in. (0.013 mm).

12.2.2 Copper screens have somewhat less absorption and intensification than lead screens, but may provide somewhat better radiographic sensitivity with higher energy above 1 MV.

12.2.3 Gold, tantalum, or other heavy metal screens may be used in cases where lead cannot be used.

12.3 Fluorescent Screens — In general, for a given source of radiation, fluorescent screens should be used only when the exposure necessary without them would be prohibitively long. In any event, if fluorescent screens must be used, they should be proven capable of achieving the required quality level. Good screen-film contact is essential for the successful use of fluorescent screens.

12.4 Screen Care — All screens should be handled carefully to avoid dents and scratches, dirt, or grease on active surfaces. Grease and lint may be removed

from lead screens with a solvent. Fluorescent screens should be cleaned in accordance with the recommendations of the manufacturer. Screens showing evidence of physical damage should be discarded.

13. Radiographic Contrast

13.1 The various radiation intensities that penetrate an object are rendered as different photographic densities in a radiograph. Using transmitted or reflected light to view a radiograph, an observed change in film density over a background is defined as contrast. Radiographic contrast depends mostly upon subject contrast and film gradient.

13.2 Subject contrast is the ratio of radiation intensities transmitted by two selected portions of a specimen.

13.3 The film gradient is the value of the slope of the tangent line drawn to a particular density point on the characteristic curve to the abscissa. Film manufacturers can furnish characteristic curves of their products.

13.4 The quality of radiography is influenced by many variables; the effects of changes in some of these variables are illustrated in Fig. 1.

14. Geometry

14.1 The focus-film distance necessary to reduce geometric unsharpness to a negligible amount depends upon the film or film-screen combinations, focal-spot size, and object-film distance. Geometric unsharpness is given [see Fig. 2(a)] by the equation:

$$U_g = Ft/d_o$$

where:

U_g = geometric unsharpness,

F = size of the radiation source,

t = specimen thickness, when in contact with the film, and

d_o = source-object distance.

NOTE 3 — d_o and t must be in the same units of measure; the units of U_g will be in the same units as F .

NOTE 4 — A nomogram for the determination of U_g is given in Fig. 3 (inch-pound units). Fig. 4 represents a nomogram in metric units.

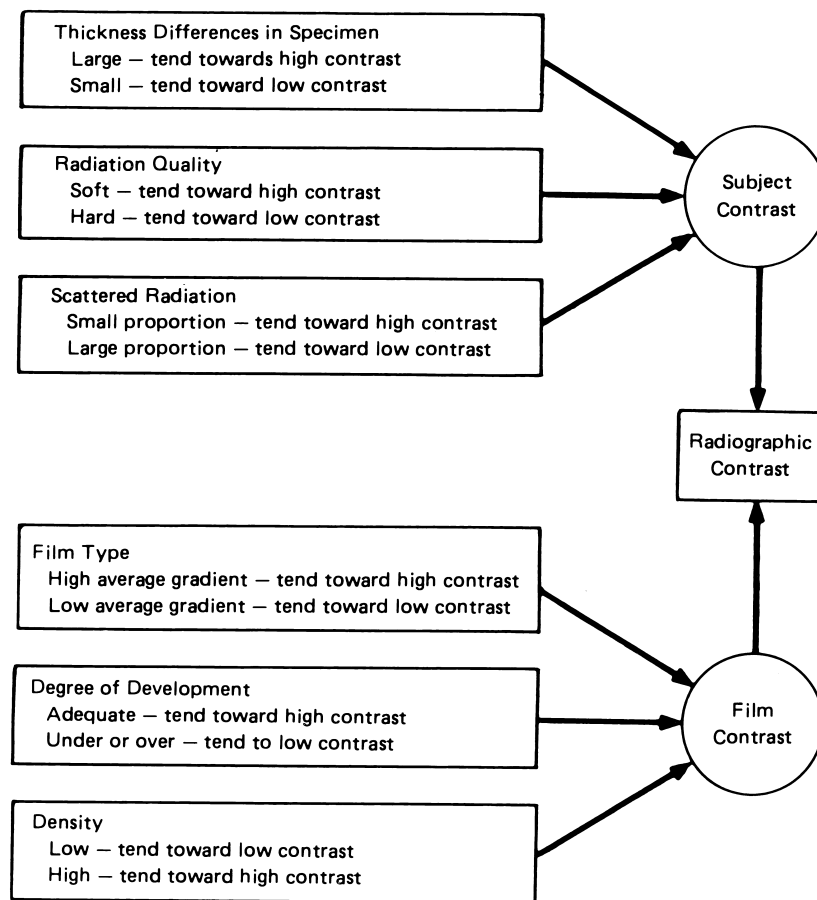
Example:

Given:

Source-film distance (d_o) = 40 in.,

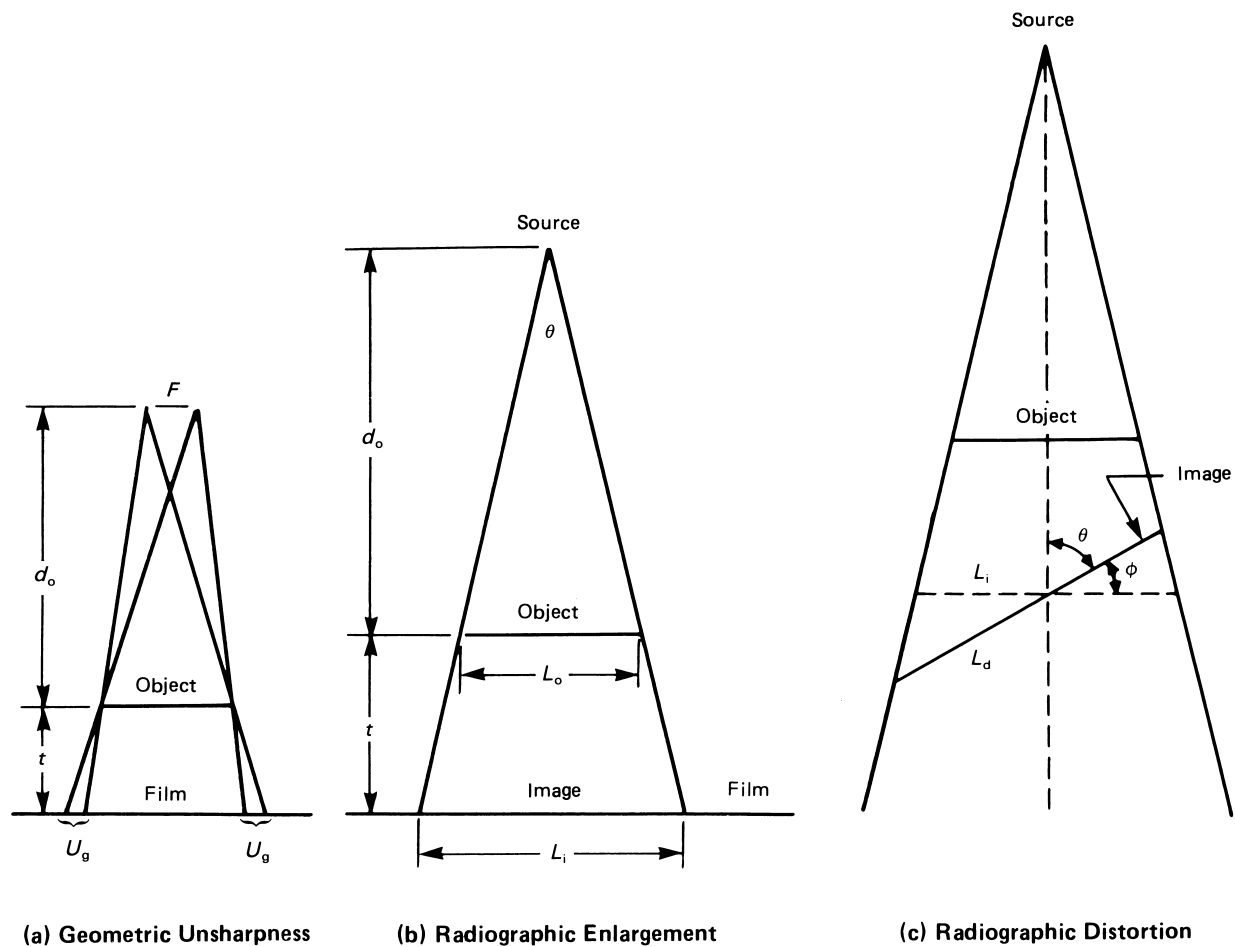
Source size (F) = 500 mils, and

Source side of specimen to film distance (t) = 1.5 in.



GENERAL NOTE: The maximum usable density on Class 1, 2, and 3 film depends on the illuminator available.

FIG. 1 EFFECTS OF CHANGES IN VARIABLES ON QUALITY OF RADIOGRAPHY



LEGEND:

 d_o = source-to-object distance t = object-to-film distance L_o = dimension of object L_i = dimension of image $U_g = Ft/d_o$

LEGEND:

 L_i = dimension of undistorted image L_d = dimension of distorted image $L_d - L_i = \Delta L$ Percentage distortion = $(\Delta L/L_i) \times 100$

$$L_i - L_o = \Delta L = 2t \times \tan 1/2\theta$$

$$\Delta L/L_o \times 100 = \text{percentage enlargement}$$

FIG. 2 EFFECTS OF OBJECT-FILM GEOMETRY

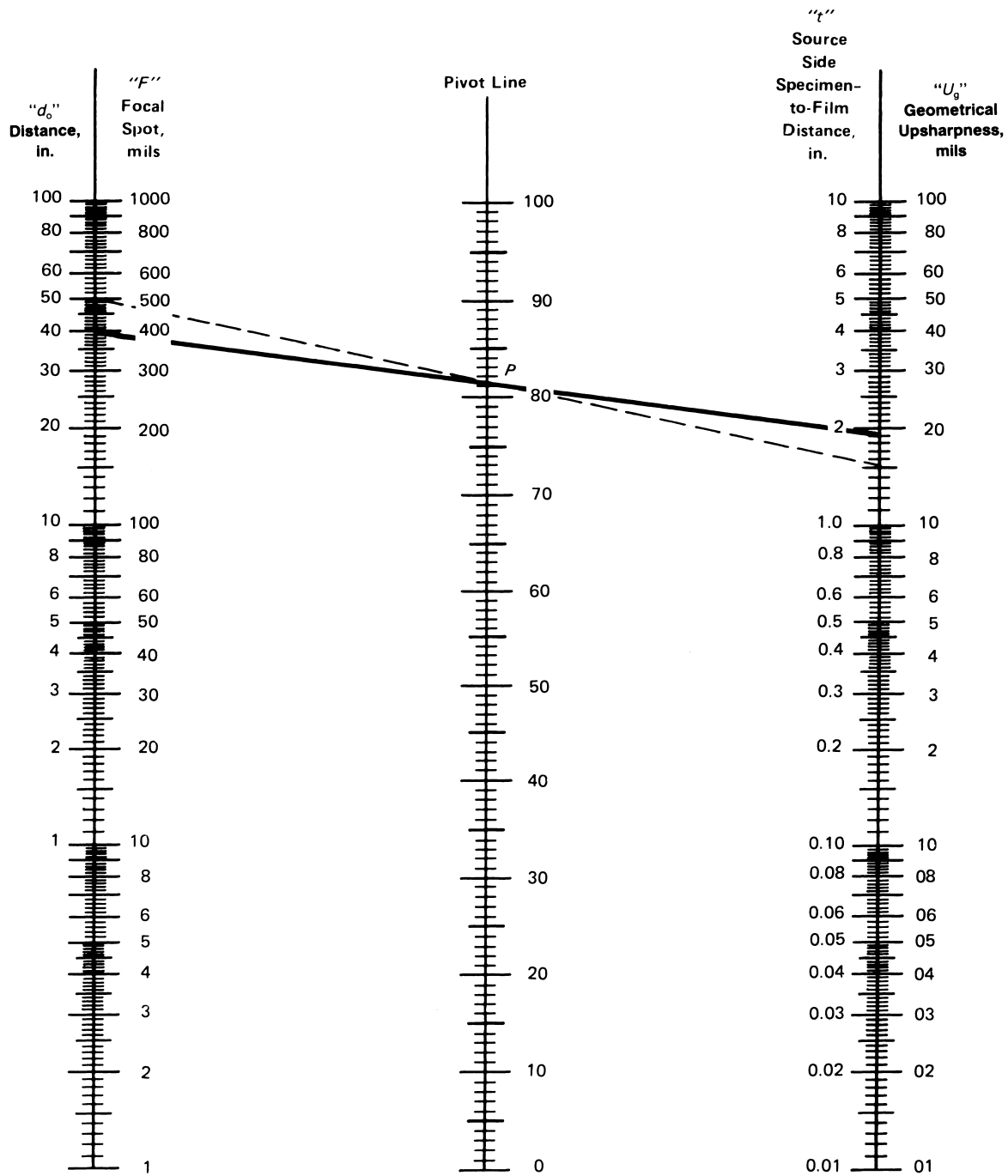


FIG. 3 NOMOGRAM FOR DETERMINING GEOMETRIC UNSHARPNESS
(Inch-Pound Units)

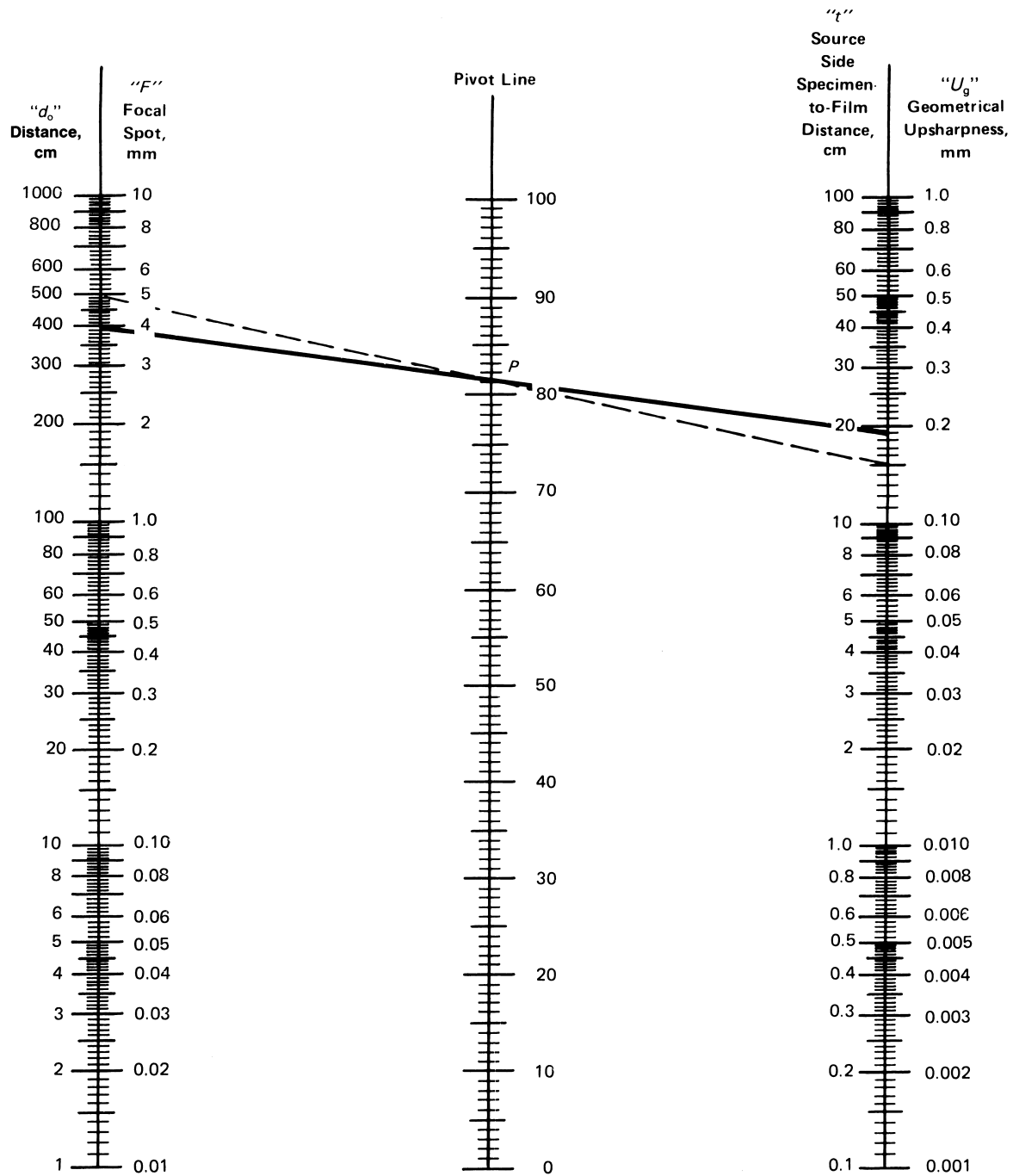


FIG. 4 NOMOGRAM FOR DETERMINING GEOMETRIC UNSHARPNESS
(Metric Units)

Draw a straight line (dashed in Fig. 3) between 500 mils on the F scale and 1.5 in. on the t scale. Note the point on intersection (P) of this line with the pivot line. Draw a straight line (solid in Fig. 3) from 40 in. on the d_o scale through point P and extend to the U_g scale. Intersection of this line with the U_g scale gives geometrical unsharpness in millimetres, which in the example is 19 mils.

Inasmuch as the source size, F , is usually fixed for a given radiation source, the value of U_g is essentially controlled by the simple d_o/t ratio.

14.2 Because X and gamma radiation is divergent, the radiographic image of an object, or of a structure within an object, will be larger than the object or the structure itself. The degree of enlargement will increase with decreasing source-object (structure) distance and with increasing object (structure)-film distance [Fig. 2(b)].

14.3 If the film is not parallel to the object, the radiographic image will be distorted because different parts of the radiographic image will be enlarged by different amounts. A measure of the degree of distortion is given by the ratio of the change in image size caused by distortion to the size of the undistorted image [Fig. 2(c)].

14.4 Final acceptance of radiographs should be based on the ability to see the prescribed penetrameter image and the specified hole. The unsharpness formula is included for information and guidance, and will operate within practical limits, but is of less consequence as d_o/t ratios increase.

15. Exposure Calculations or Charts

15.1 Development or procurement of an exposure chart or calculator is the responsibility of the individual laboratory.

15.2 The essential elements of an exposure chart or calculator must relate the following:

- 15.2.1** Source or machine,
- 15.2.2** Material type,
- 15.2.3** Material thickness,
- 15.2.4** Film type (relative speed),
- 15.2.5** Film density (see Note 5),
- 15.2.6** Source or focus-film distance,
- 15.2.7** Kilovoltage or isotope type,

NOTE 5 — For detailed information of film density and density measurement calibration, see Practice E 1079.

15.2.8 Screen type and thickness,

15.2.9 Curies or milliamperes,

15.2.10 Time of exposure,

15.2.11 Filter (in the primary beam),

15.2.12 Time-temperature development for hand processing; access time for automatic processing; time-temperature development for dry processing, and

15.2.13 Processing chemistry brand name, if applicable.

15.3 The essential elements listed in 15.2 will be accurate for isotopes of the same type, but will vary with X-ray equipment of the same kilovoltage and milliamperage rating.

15.4 Exposure charts should be developed for each X-ray machine and corrected each time a major component is replaced, such as the X-ray tube or high-voltage transformer.

15.5 The exposure chart should be corrected when the processing chemicals are changed to a different manufacturer's brand or the time-temperature relationship of the processor may be adjusted to suit the exposure chart. The exposure chart, when using a dry processing method, should be corrected based upon the time-temperature changes of the processor.

16. Technique File

16.1 It is recommended that a radiographic technique log or record containing the essential elements be maintained.

16.2 The radiographic technique log or record should contain the following:

- 16.2.1** Description or sketch of the object,
- 16.2.2** Material type and thickness,
- 16.2.3** Source or focus-film distance,
- 16.2.4** Film type,
- 16.2.5** Film density,
- 16.2.6** Screen type and thickness,
- 16.2.7** Isotope or X-ray machine identification,
- 16.2.8** Curie or milliamperage minutes,
- 16.2.9** Film placement for nonstandard items,
- 16.2.10** Source position for nonstandard items,

16.2.11 Penetrameter and shim thickness,

16.2.12 Special masking or filters,

16.2.13 Collimator or field limitation device, and

16.2.14 Processing method.

16.3 The recommendations of 16.2 are not mandatory, but are essential in reducing the overall cost of radiography, and serve as a communication link between the radiographic interpreter and the radiographic operator.

17. Penetrameters (Image Quality Indicators)

17.1 The selection and placement of penetrameters shall be in accordance with applicable standards Method E 142, Test Method E 747, and Practices E 801 and E 1025.

17.2 Another image quality indicator (IQI) may be found in Test Method E 746 for determining relative image quality response of industrial X-ray films at 200 KEV.

17.2.1 However, the E 746 Equivalent Penetrameter Sensitivity (EPS) plaque may be used to study the effects of various radiographic variables on radiographic system EPS performance.

17.2.2 For example, multiple X-ray machines may be observed for their effect on EPS by holding film and processing constant and taking image quality exposures with all the X-ray machines. The machines would be set for the given exposure condition in Test Method E 746 and film density equalized. By reading the resultant films, the relative EPS variations between machines may be determined.

17.2.3 Exposure condition variables may also be studied using this plaque.

17.2.4 While Test Method E 746 plaque can be useful in quantifying relative radiographic image quality, these other applications of the plaque may be useful.

18. Identification of and Location Markers on Radiographs

18.1 Identification of Radiographs:

18.1.1 Each radiograph must be identified uniquely so that there is a permanent correlation between the part radiographed and the film. The type of identification and method by which identification is achieved shall be as agreed upon between the customer and inspector.

18.1.2 The minimum identification should at least include the following: the radiographic facility's name, the date, part number and serial number, if used, for unmistakable identification of radiographs with the specimen. The letter *R* should be used to designate a radiograph of a repair area, and may include -1 , -2, etc., for the number of repair.

18.2 Location Markers:

18.2.1 Location markers (that is, lead or high-atomic number metals or letters that are to appear as images on the radiographic film) should be placed on the part being examined, whenever practical, and not on the cassette. Their exact locations should also be marked on the surface of the part being radiographed, thus permitting the area of interest to be located accurately on the part, and they should remain on the part during radiographic inspection. Their exact location may be permanently marked in accordance with the customer's requirements.

18.2.2 Location markers are also used in assisting the radiographic interpreter in marking off defective areas of components, castings, or defects in weldments; also, sorting good and rejectable items when more than one item is radiographed on the same film.

18.2.3 Sufficient markers must be used to provide evidence on the radiograph that the required coverage of the object being examined has been obtained, and that overlap is evident, especially during radiography of weldments and casting.

18.2.4 Parts that must be identified permanently may have the serial numbers or section numbers, or both, stamped or written upon them with a marking pen with a special indelible ink, engraved, die stamped, or etched. In any case, the part should be marked in an area not to be removed in subsequent fabrication. If die stamps are used, caution is required to prevent breakage or future fatigue failure. The lowest stressed surface of the part should be used for this stamping. Where marking or stamping of the part is not permitted for some reason, a marked reference drawing or shooting sketch is recommended.

PART II — PROTECTION AND CARE OF UNPROCESSED FILM

19. Storage of Film

19.1 Unexposed films should be stored in such a manner that they are protected from the effects of light, pressure, excessive heat, excessive humidity, damaging

fumes or vapors, or penetrating radiation. Film manufacturers should be consulted for detailed recommendations on film storage. Storage of film should be on a “first in,” “first out” basis.

19.2 More detailed information on film storage is provided in Guide E 1254.

20. Safelight Test

20.1 Films should be handled under safelight conditions in accordance with the film manufacturer’s recommendations. ANSI PH2.22 can be used to determine the adequacy of safelight conditions in a darkroom.

21. Cleanliness and Film Handling

21.1 Cleanliness is one of the most important requirements for good radiography. Cassettes and screens must be kept clean, not only because dirt retained may cause exposure or processing artifacts in the radiographs, but because such dirt may also be transferred to the loading bench, and subsequently to other film or screens.

21.2 The surface of the loading bench must be kept clean. Where manual processing is used, cleanliness will be promoted by arranging the darkroom with processing facilities on one side and film-handling facilities on the other. The darkroom will then have a wet side and a dry side and the chance of chemical contamination of the loading bench will be relatively slight.

21.3 Films should be handled only at their edges, and with dry, clean hands to avoid finger marks on film surfaces.

21.4 Sharp bending, excessive pressure, and rough handling of any kind must be avoided.

PART III — PROCESSING FILMS AND VIEWING AND STORING RADIOGRAPHS

22. Film Processing, General

22.1 To produce a satisfactory radiograph, the care used in making the exposure *must* be followed by equal care in processing. The most careful radiographic techniques can be nullified by incorrect or improper darkroom procedures.

22.2 More detailed information on film processing is provided in Guide E 999.

23. Automatic Processing

23.1 Automatic Processing — The essence of the automatic processing system is control. The processor maintains the chemical solutions at the proper temperature, agitates and replenishes the solutions automatically, and transports the films mechanically at a carefully controlled speed throughout the processing cycle. Film characteristics must be compatible with processing conditions. It is, therefore, essential that the recommendations of the film, processor, and chemical manufacturers be followed.

23.2 Automatic Processing, Dry — The essence of dry automatic processing is the precise control of development time and temperature which results in reproducibility of radiographic density. Film characteristics must be compatible with processing conditions. It is, therefore, essential that the recommendations of the film and processor manufacturers be followed.

24. Manual Processing

24.1 Film and chemical manufacturers should be consulted for detailed recommendations on manual film processing. This section outlines the steps for one acceptable method of manual processing.

24.2 Preparation — No more film should be processed than can be accommodated with a minimum separation of $\frac{1}{2}$ in. (12.7 mm). Hangers are loaded and solutions stirred before starting development.

24.3 Start of Development — Start the timer and place the films into the developer tank. Separate to a minimum distance of $\frac{1}{2}$ in. (12.7 mm) and agitate in two directions for about 15 s.

24.4 Development — Normal development is 5 to 8 min at 68°F (20°C). Longer development time generally yields faster film speed and slightly more contrast. The manufacturer’s recommendation should be followed in choosing a development time. When the temperature is higher or lower, development time must be changed. Again, consult manufacturer-recommended development time versus temperature charts. Other recommendations of the manufacturer to be followed are replenishment rates, renewal of solutions, and other specific instructions.

24.5 Agitation — Shake the film horizontally and vertically, ideally for a few seconds each minute during development. This will help film develop evenly.

24.6 Stop Bath or Rinse — After development is complete, the activity of developer remaining in the

emulsion should be neutralized by an acid stop bath or, if this is not possible, by rinsing with vigorous agitation in clear water. Follow the film manufacturer's recommendation of stop bath composition (or length of alternative rinse), time immersed, and life of bath.

24.7 Fixing — The films must not touch one another in the fixer. Agitate the hangers vertically for about 10 s and again at the end of the first minute, to ensure uniform and rapid fixation. Keep them in the fixer until fixation is complete (that is, at least twice the clearing time), but not more than 15 min in relatively fresh fixer. Frequent agitation will shorten the time of fixation.

24.8 Fixer Neutralizing — The use of a hypo eliminator or fixer neutralizer between fixation and washing may be advantageous. These materials permit a reduction of both time and amount of water necessary for adequate washing. The recommendations of the manufacturers as to preparation, use, and useful life of the baths should be observed rigorously.

24.9 Washing — The washing efficiency is a function of wash water, its temperature, and flow, and the film being washed. Generally, washing is very slow below 60°F (16°C). When washing at temperatures above 85°F (30°C), care should be exercised not to leave films in the water too long. The films should be washed in batches without contamination from new film brought over from the fixer. If pressed for capacity, as more films are put in the wash, partially washed film should be moved in the direction of the inlet.

24.9.1 The cascade method of washing uses less water and gives better washing for the same length of time. Divide the wash tank into two sections (may be two tanks). Put the films from the fixer in the outlet section. After partial washing, move the batch of film to the inlet section. This completes the wash in fresh water.

24.9.2 For specific washing recommendations, consult the film manufacturer.

24.10 Wetting Agent — Dip the film for approximately 30 s in a wetting agent. This makes water drain evenly off film, which facilitates quick, even drying.

24.11 Residual Fixer Concentrations — If the fixing chemicals are not removed adequately from the film, they will in time cause staining or fading of the developed image. Residual fixer concentrations permissible depend upon whether the films are to be kept for commercial purposes (3 to 10 years) or must be of archival quality. Archival quality processing is desirable for all radiographs whenever average relative

humidity and temperature are likely to be excessive, as is the case in tropical and subtropical climates. The method of determining residual fixer concentrations may be ascertained by reference to ANSI PH4.8, PH1.28, and PH1.41.

24.12 Drying — Drying is a function of (1) film (base and emulsion); (2) processing (hardness of emulsion after washing, use of wetting agent); and (3) drying air (temperature, humidity, flow). Manual drying can vary from still air drying at ambient temperature to as high as 140°F (60°C) with air circulated by a fan. Film manufacturers should again be contacted for recommended drying conditions. Take precaution to tighten film on hangers, so that it cannot touch in the dryer. Too hot a drying temperature at low humidity can result in uneven drying and should be avoided.

25. Testing Developer

25.1 It is desirable to monitor the activity of the radiographic developing solution. This can be done by periodic development of film strips exposed under carefully controlled conditions, to a graded series of radiation intensities or time, or by using a commercially available strip carefully controlled for film speed and latent image fading.

26. Viewing Radiographs

26.1 Transmission — The illuminator must provide light of an intensity that will illuminate the average density areas of the radiographs without glare and it must diffuse the light evenly over the viewing area. Commercial fluorescent illuminators are satisfactory for radiographs of moderate density; however, high light intensity illuminators are available for densities up to 3.5 or 4.0. Masks should be available to exclude any extraneous light from the eyes of the viewer when viewing radiographs smaller than the viewing port or to cover low-density areas.

26.2 Reflection — Radiographs on a translucent or opaque backing may be viewed by reflected light. It is recommended that the radiograph be viewed under diffuse lighting conditions to prevent excess glare. Optical magnification can be used in certain instances to enhance the interpretation of the image.

27. Viewing Room

27.1 Subdued lighting, rather than total darkness, is preferable in the viewing room. The brightness of the surroundings should be about the same as the area of interest in the radiograph. Room illumination must be so arranged that there are no reflections from the surface of the film under examination.

28. Storage of Processed Radiographs

28.1 Radiographs should be stored using the same care as for any other valuable record.

28.2 Envelopes having an edge seam, rather than a center seam, and joined with a nonhygroscopic adhesive, are preferred, since occasional staining and fading of the image is caused by certain adhesives used in the manufacture of envelopes (see ANSI PH1.53).

PART IV — RECORDS, REPORTS, AND IDENTIFICATION OF ACCEPTED MATERIAL

29. Records

29.1 It is recommended that an X-ray log (a log may consist of a card file, punched card system, a book, or other record) constituting a record of each job performed, be maintained. This record should comprise, initially, a job number (which should appear also on the films), the identification of the parts, material or area radiographed, the date the films are exposed, and a complete record of the radiographic procedure, in

sufficient detail so that any radiographic techniques may be duplicated readily. If calibration data, or other records such as card files or procedures, are used to determine the procedure, the log need refer only to the appropriate data or other record. Subsequently, the interpreter's findings and disposition (acceptance or rejection), if any, and his initials, should be entered for each job.

30. Reports

30.1 When written reports of radiographic examinations are required, they should include the following, plus such other items as may be agreed upon:

30.1.1 Identification of parts, material, or area.

30.1.2 Radiographic job number.

30.1.3 Findings and disposition, if any. This information can be obtained directly from the log.

31. Identification of Completed Work

31.1 Whenever radiography is an inspective (rather than investigative) operation whereby material is accepted or rejected, all parts and material that have been accepted should be marked permanently, if possible, with a characteristic identifying symbol which will indicate to subsequent or final inspectors the fact of radiographic acceptance.

31.2 Whenever possible, the completed radiographs should be kept on file for reference. The custody of radiographs and the length of time they are preserved should be agreed upon between the contracting parties.

APPENDIX (Nonmandatory Information)

X1. USE OF FLUORESCENT SCREENS

X1.1 Description — Fluorescent intensifying screens have a cardboard or plastic support coated with a uniform layer of inorganic phosphor (crystalline substance). The support and phosphor are held together by a radiotransparent binding material. Fluorescent screens derive their name from the fact that their phosphor crystals “fluoresce” (emit visible light) when struck by X or gamma radiation. Some phosphors like calcium tungstate (CaWO_4) give off blue light while others known as rare earth emit light green.

X1.2 Purpose and Film Types — Fluorescent screen exposures are usually much shorter than those made without screens or with lead intensifying screens, because radiographic films generally are more responsive to visible light than to direct X-radiation, gamma radiation, and electrons.

X1.2.1 Films fall into one of two categories: non-screen type film having moderate light response, and screen type film specifically sensitized to have a very high blue or green light response. Fluorescent screens can reduce conventional exposures by as much as 150 times, depending on film type.

X1.3 Image Quality and Use — The image quality associated with fluorescent screen exposures is a function of sharpness, mottle, and contrast. Screen sharpness depends on phosphor crystal size, thickness of the crystal layer, and the reflective base coating. Each crystal emits light relative to its size and in all directions thus producing a relative degree of image unsharpness. To minimize this unsharpness, screen to film contact should be as intimate as possible. Mottle adversely affects image quality in two ways. First, a “quantum” mottle is dependent upon the amount of X or gamma radiation actually absorbed by the fluorescent screen, that is, faster screen/film systems lead to greater mottle and poorer image quality. A “structural” mottle, which is a function of crystal size, crystal uniformity, and

layer thickness, is minimized by using screens having small, evenly spaced crystals in a thin crystalline layer. Fluorescent screens are highly sensitive to longer wavelength scattered radiation. Consequently, to maximize contrast when this non-image forming radiation is excessive, fluorometallic intensifying screens or fluorescent screens backed by lead screens of appropriate thickness are recommended. Screen technology has seen significant advances in recent years, and today’s fluorescent screens have smaller crystal size, more uniform crystal packing, and reduced phosphor thickness. This translates into greater screen/film speed with reduced unsharpness and mottle. These improvements can represent some meaningful benefits for industrial radiography, as indicated by the three examples as follows:

X1.3.1 Reduced Exposure (Increased Productivity) — There are instances where prohibitively long exposure times make conventional radiography impractical. An example is the inspection of thick, high atomic number materials with low curie isotopes. Depending on many variables, exposure time may be reduced by factors ranging from $2\times$ to $105\times$ when the appropriate fluorescent screen/film combination is used.

X1.3.2 Improved Safety Conditions (Field Sites) — Because fluorescent screens provide reduced exposure, the length of time that non-radiation workers must evacuate a radiographic inspection site can be reduced significantly.

X1.3.3 Extended Equipment Capability — Utilizing the speed advantage of fluorescent screens by translating it into reduced energy level. An example is that a 150 kV X-ray tube may do the job of a 300 kV tube, or that iridium 192 may be used in applications normally requiring cobalt 60. It is possible for overall image quality to be better at the lower kV with fluorescent screens than at a higher energy level using lead screens.

STANDARD PRACTICE FOR DESIGN, MANUFACTURE, AND MATERIAL GROUPING CLASSIFICATION OF WIRE IMAGE QUALITY INDICATORS (IQI) USED FOR RADIOLOGY



SE-747



(Identical with ASTM Specification E 747-97)

1. Scope

1.1 This practice covers the design, material grouping classification, and manufacture of wire image quality indicators (IQI) used to indicate the quality of radiologic images.

1.2 This practice is applicable to X-ray and gamma-ray radiology.

1.3 This practice covers the use of wire penetrameters as the controlling image quality indicator for the material thickness range from 6.4 to 152 mm (0.25 to 6.0 in.).

1.4 The values stated in inch-pound units are to be regarded as standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

- B 139 Specification for Phosphor Bronze Rod, Bar, and Shapes
- B 150 Specification for Aluminum Bronze Rod, Bar, and Shapes
- B 161 Specification for Nickel Seamless Pipe and Tube
- B 164 Specification for Nickel-Copper Alloy Rod, Bar, and Wire

B 166 Specification for Nickel-Chromium-Iron Alloys (UNS N06600, N06601, and N06690) and Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617) Rod, Bar, and Wire

E 1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiography

E 1316 Terminology for Nondestructive Examinations

3. Terminology

3.1 Definitions — The definitions of terms in Terminology E 1316, Section D, relating to gamma and x-radiology, shall apply to the terms used in this practice.

4. Wire IQI Requirements

4.1 The quality of all levels of examination shall be determined by a set of wires conforming to the following requirements:

4.1.1 Wires shall be fabricated from materials or alloys identified or listed in accordance with 7.2. Other materials may be used in accordance with 7.3.

4.1.2 The IQI consists of sets of wires arranged in order of increasing diameter. The diameter sizes specified in Table 1 are established from a consecutive series of numbers taken in general from the ISO/R 10 series. The IQI shall be fabricated in accordance with the requirements specified in Figs. 1 through 8 and

TABLE 1
WIRE IQI SIZES AND WIRE IDENTITY NUMBERS

SET A		SET B	
Wire Diameter, in. (mm)	Wire Identity	Wire Diameter, in. (mm)	Wire Identity
0.0032 (0.08) ⁴	1	0.010 (0.25)	6
0.004 (0.1)	2	0.013 (0.33)	7
0.005 (0.13)	3	0.016 (0.4)	8
0.0063 (0.16)	4	0.020 (0.51)	9
0.008 (0.2)	5	0.025 (0.64)	10
0.010 (0.25)	6	0.032 (0.81)	11
SET C		SET D	
Wire Diameter, in. (mm)	Wire Identity	Wire Diameter, in. (mm)	Wire Identity
0.032 (0.81)	11	0.10 (2.5)	16
0.040 (1.02)	12	0.126 (3.2)	17
0.050 (1.27)	13	0.160 (4.06)	18
0.063 (1.6)	14	0.20 (5.1)	19
0.080 (2.03)	15	0.25 (6.4)	20
0.100 (2.5)	16	0.32 (8)	21

⁴The 0.0032 wire may be used to establish a special quality level as agreed upon between the purchaser and the supplier.

TABLE 2
WIRE DIAMETER TOLERANCES (mm)

Wire Diameter (<i>d</i>), mm	Tolerance, mm
0.000 < <i>d</i> ≤ 0.125	±0.0025
0.125 < <i>d</i> ≤ 0.25	±0.005
0.25 < <i>d</i> ≤ 0.5	±0.01
0.50 < <i>d</i> ≤ 1.6	±0.02
1.6 < <i>d</i> ≤ 4	±0.03
4.0 < <i>d</i> ≤ 8	±0.05

TABLE 3
WIRE DIAMETER TOLERANCES (in.)

Wire Diameter (<i>d</i>), in.	Tolerance, in.
0.000 < <i>d</i> ≤ 0.005	±0.0001
0.005 < <i>d</i> ≤ 0.010	±0.0002
0.010 < <i>d</i> ≤ 0.020	±0.0004
0.020 < <i>d</i> ≤ 0.063	±0.0008
0.063 < <i>d</i> ≤ 0.160	±0.0012
0.160 < <i>d</i> ≤ 0.320	±0.0020

Tables 1, 2, and 3. IQIs previously manufactured to the requirements of Annex A1 may be used as an alternate provided all other requirements of this practice are met.

4.1.3 Image quality indicator (IQI) designs other than those shown in Figs. 1 through 8 and Annex A1 are permitted by contractual agreement. If an IQI set as listed in Table 1 or Annex A1 is modified in size, it must contain the grade number, set identity, and essential wire. It must also contain two additional wires that are the next size larger and the next size smaller as specified in the applicable set listed in Table 1.

4.1.4 Each set must be identified using letters and numbers made of industrial grade lead or of a material of similar radiographic density. Identification shall be as shown in Figs. 1 through 8 or Annex A1, unless otherwise specified by contractual agreement.

5. Image Quality Indicator (IQI) Procurement

5.1 When selecting IQIs for procurement, the following factors should be considered:

5.1.1 Determine the alloy group(s) of the material to be examined.

5.1.2 Determine the thickness or thickness range of the material(s) to be examined.

5.1.3 Select the applicable IQIs that represent the required IQI thickness(s) and alloy(s).

6. Image Quality Levels

6.1 The quality level required using wire penetrameters shall be equivalent to the 2-2T level of Practice E 1025 for hole-type IQIs unless a higher or lower quality level is agreed upon between purchaser and supplier. Table 4 provides a list of various hole-type IQIs and the diameter of wires of corresponding equivalent penetrometer sensitivity (EPS) with the applicable 1T, 2T, and 4T holes in the IQI. This table can be used for determining 1T, 2T, and 4T quality levels. Appendix X1 gives the equation for calculating other equivalencies if needed.

6.2 In specifying quality levels, the contract, purchase order, product specification, or drawing should clearly indicate the thickness of material to which the quality level applies. Careful consideration of required quality levels is particularly important.

7. Material Groups

7.1 General:

7.1.1 Materials have been designated in eight groups based on their radiographic absorption character-

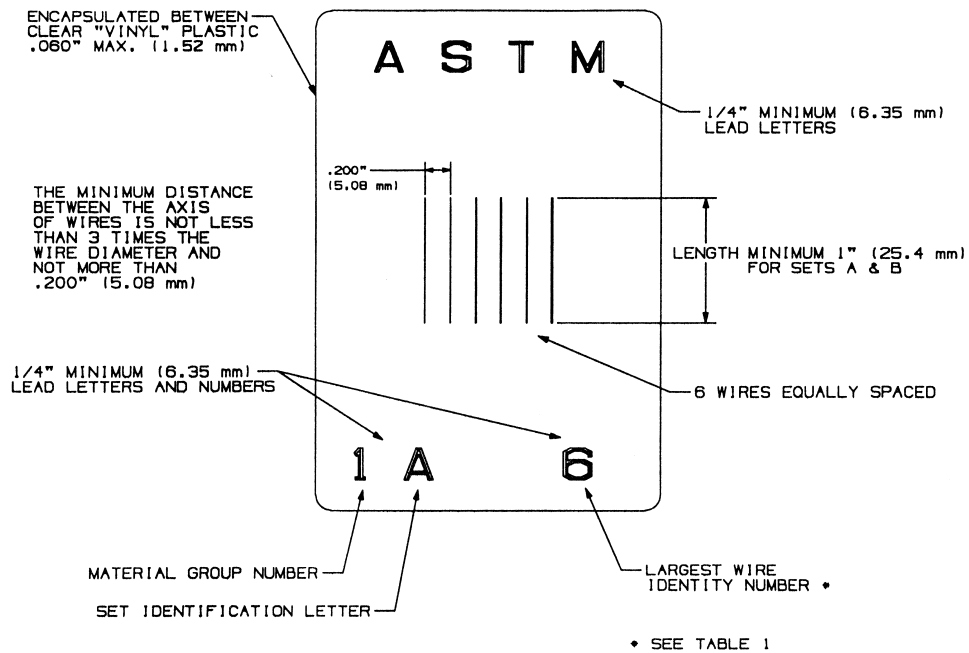


FIG. 1 SET A/ALTERNATE 1

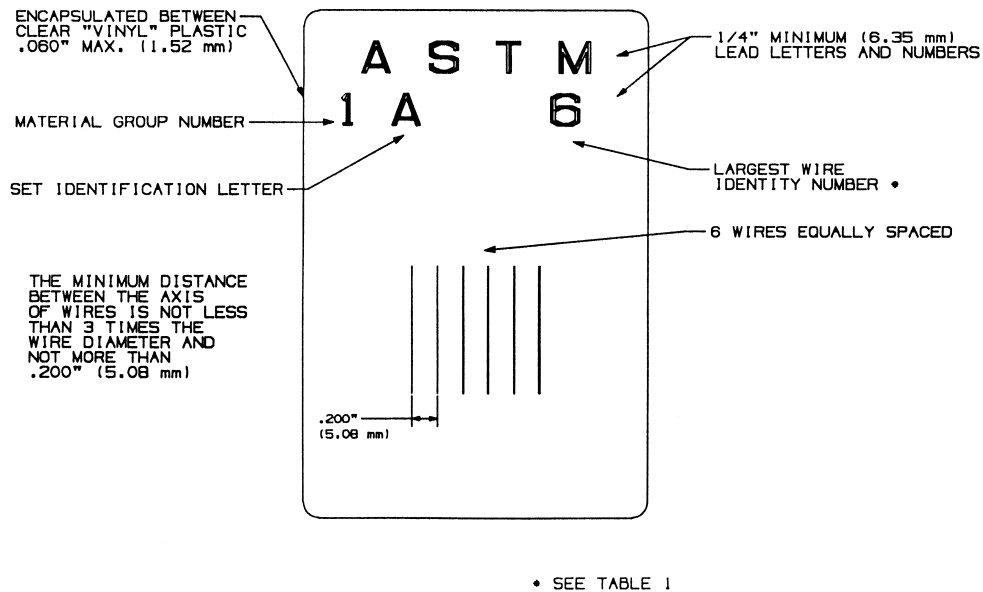


FIG. 2 SET A/ALTERNATE 2

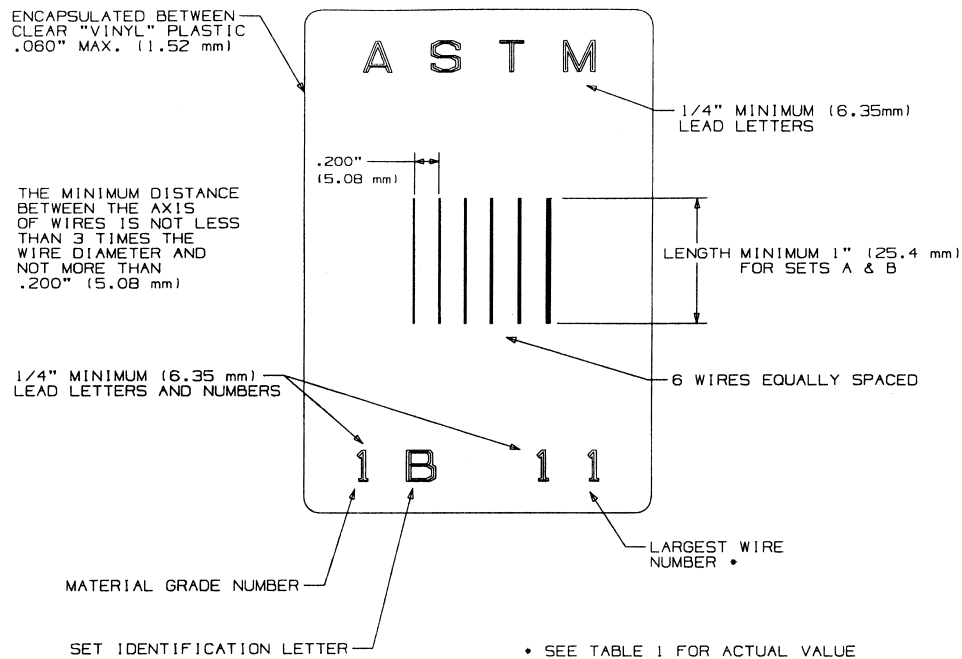


FIG. 3 SET B/ALTERNATE 1

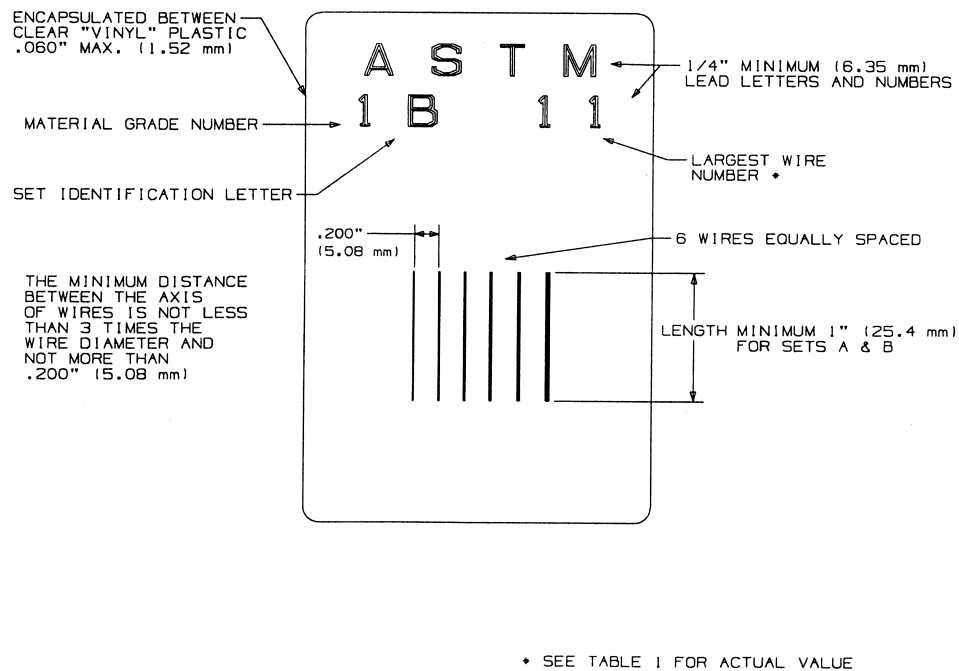


FIG. 4 SET B/ALTERNATE 2

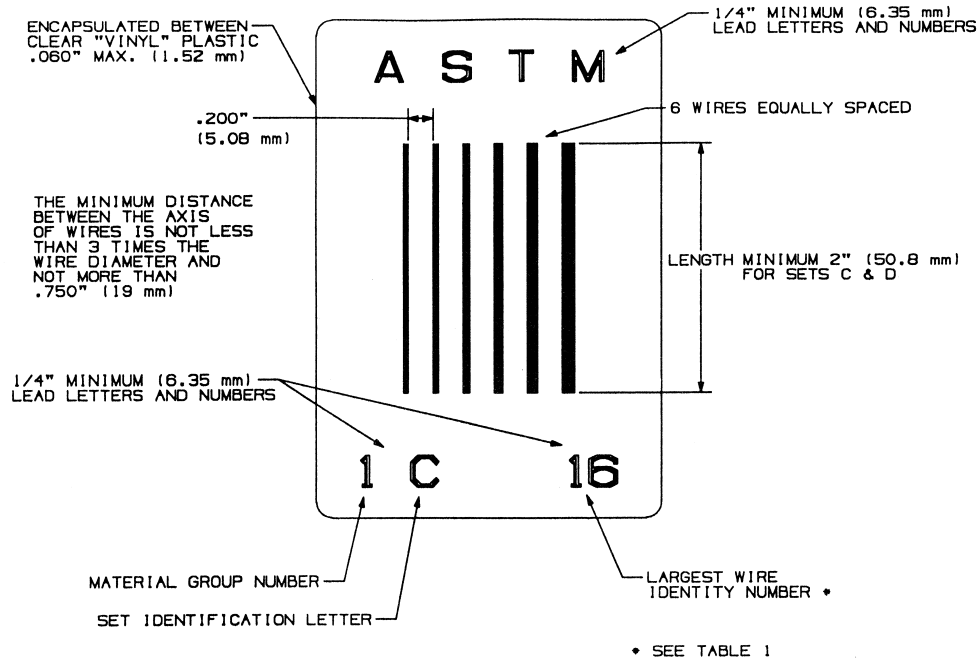


FIG. 5 SET C/ALTERNATE 1

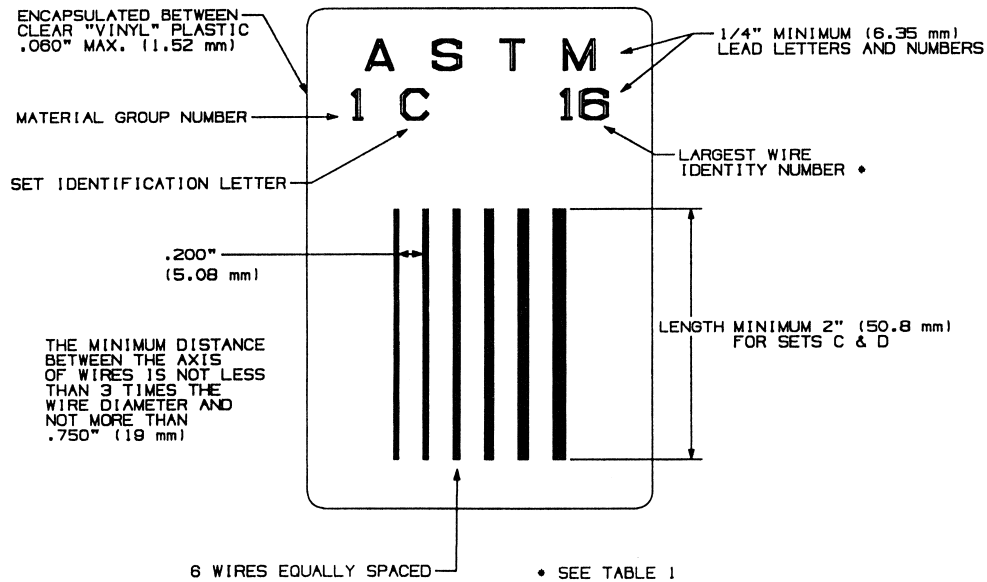


FIG. 6 SET C/ALTERNATE 2

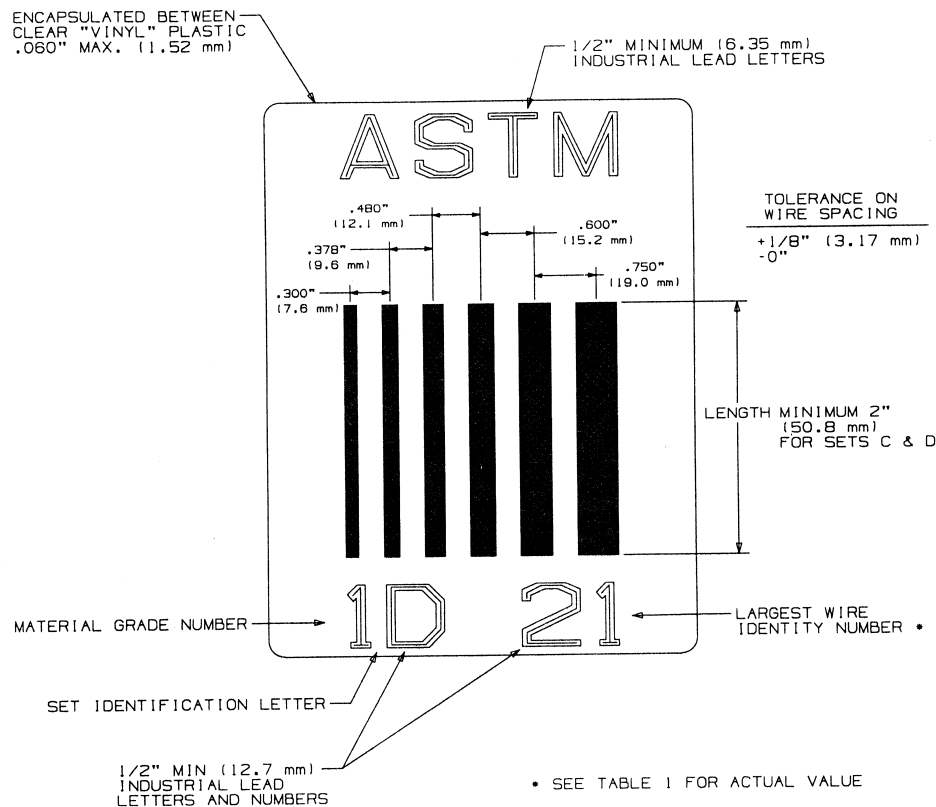


FIG. 7 SET D/ALTERNATE 1

istics: groups 03, 02, and 01 for light metals and groups 1 through 5 for heavy metals.

7.1.2 The light metal groups, magnesium (Mg), aluminum (Al), and titanium (Ti), are identified 03, 02, and 01 respectively, for their predominant alloying constituent. The materials are listed in order of increasing radiation absorption.

7.1.3 The heavy metal groups, steel, copper-base, nickel-base, and kindred alloys, are identified 1 through 5. The materials increase in radiation absorption with increasing numerical designation.

7.1.4 Common trade names or alloy designations have been used for clarification of the pertinent materials.

7.1.5 The materials from which the IQI for the group are to be made are designated in each case and these IQIs are applicable for all materials listed in that group. In addition, any group IQI may be used for any material with a higher group number, provided the applicable quality level is maintained.

7.2 Materials Groups:

7.2.1 Materials Group 01:

7.2.1.1 Image quality indicators (IQIs) shall be made of titanium or titanium shall be the predominant alloying constituent.

7.2.1.2 Use on all alloys of which titanium is the predominant alloying constituent.

7.2.2 Materials Group 02:

7.2.2.1 Image quality indicators (IQIs) shall be made of aluminum or aluminum shall be the predominant alloying constituent.

7.2.2.2 Use on all alloys of which aluminum is the predominant alloying constituent.

7.2.3 Materials Group 03:

7.2.3.1 Image quality indicators (IQIs) shall be made of magnesium or magnesium shall be the predominant alloying constituent.

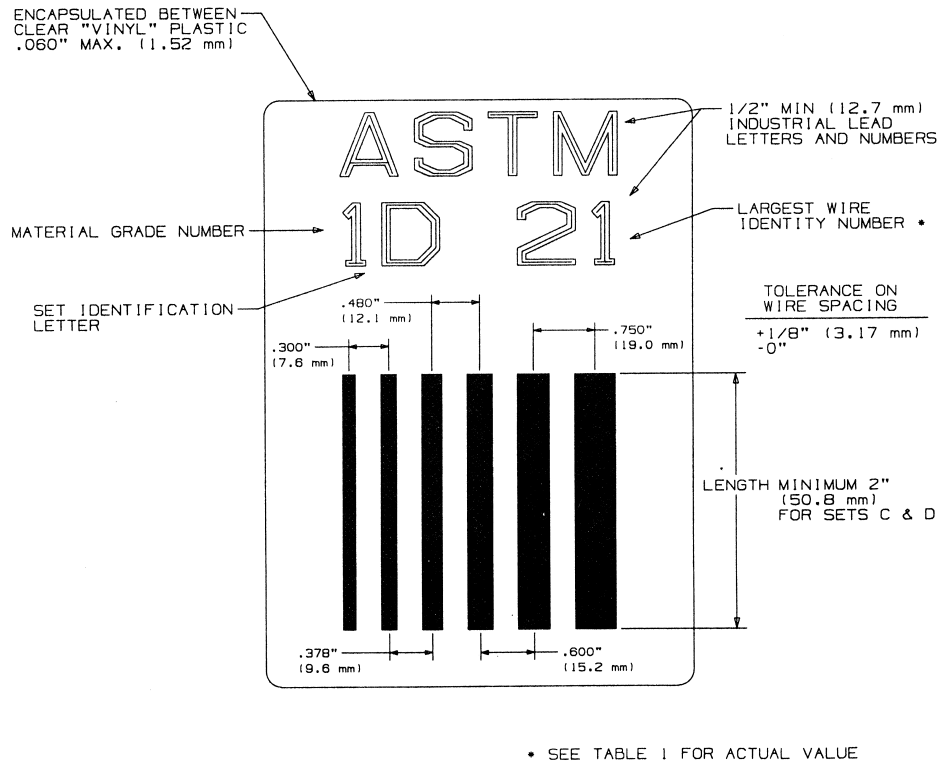


FIG. 8 SET D/ALTERNATE 2

7.2.3.2 Use on all alloys of which magnesium is the predominant alloying constituent.

7.2.4 Materials Group 1:

7.2.4.1 Image quality indicators (IQIs) shall be made of carbon steel or Type 300 series stainless steel.

7.2.4.2 Use on all carbon steel, low-alloy steels, stainless steels, and manganese-nickel-aluminum bronze (Superston).

7.2.5 Materials Group 2:

7.2.5.1 Image quality indicators (IQIs) shall be made of aluminum bronze (Alloy No. 623 of Specification B 150) or equivalent, or nickel-aluminum bronze (Alloy No. 630 of Specification B 150) or equivalent.

7.2.5.2 Use on all aluminum bronzes and all nickel-aluminum bronzes.

7.2.6 Materials Group 3:

7.2.6.1 Image quality indicators (IQIs) shall be made of nickel-chromium-iron alloy (UNS No. N06600) (Inconel). (See Specification B 166.)

7.2.6.2 Use on nickel-chromium-iron alloy and 18% nickel-maraging steel.

7.2.7 Materials Group 4:

7.2.7.1 Image quality indicators (IQIs) shall be made of 70 to 30 nickel-copper alloy (Monel) (Class A or B of Specification B 164) or equivalent, or 70 to 30 copper-nickel alloy (Alloy G of Specification B 161) or equivalent.

7.2.7.2 Use on nickel, copper, all nickel-copper series, or copper-nickel series of alloys, and all brasses (copper-zinc alloys). Group 4 IQIs may include the leaded brasses since leaded brass increases in attenuation with increase in lead content. This would be equivalent to using a lower group IQI.

7.2.8 Materials Group 5:

7.2.8.1 Image quality indicators (IQIs) shall be made of tin bronze (Alloy D of Specification B 139).

7.2.8.2 Use on tin bronzes including gun-metal and valve bronze, or leaded-tin bronze of higher lead content than valve bronze. Group 5 IQIs may include

TABLE 4
WIRE SIZES EQUIVALENT TO CORRESPONDING 1T, 2T, AND 4T HOLES IN VARIOUS HOLE TYPE PLAQUES

Plaque Thickness, in. (mm)	Plaque IQI Identification Number	Diameter of wire with EPS of hole in plaque, in. (mm)		
		1T	2T	4T
0.005 (0.13)	5		0.0038 (0.09)	0.006 (0.15)
0.006 (0.16)	6		0.004 (0.10)	0.0067 (0.18)
0.008 (0.20)	8	0.0032 (0.08)	0.005 (0.13)	0.008 (0.20)
0.009 (0.23)	9	0.0035 (0.09)	0.0056 (0.14)	0.009 (0.23)
0.010 (0.25)	10	0.004 (0.10)	0.006 (0.15)	0.010 (0.25)
0.012 (0.30)	12	0.005 (0.13)	0.008 (0.20)	0.012 (0.28)
0.015 (0.38)	15	0.0065 (0.16)	0.010 (0.25)	0.016 (0.41)
0.017 (0.43)	17	0.0076 (0.19)	0.012 (0.28)	0.020 (0.51)
0.020 (0.51)	20	0.010 (0.25)	0.015 (0.38)	0.025 (0.63)
0.025 (0.64)	25	0.013 (0.33)	0.020 (0.51)	0.032 (0.81)
0.030 (0.76)	30	0.016 (0.41)	0.025 (0.63)	0.040 (1.02)
0.035 (0.89)	35	0.020 (0.51)	0.032 (0.81)	0.050 (1.27)
0.040 (1.02)	40	0.025 (0.63)	0.040 (1.02)	0.063 (1.57)
0.050 (1.27)	50	0.032 (0.81)	0.050 (1.27)	0.080 (2.03)
0.060 (1.52)	60	0.040 (1.02)	0.063 (1.57)	0.100 (2.54)
0.070 (1.78)	70	0.050 (1.27)	0.080 (2.03)	0.126 (3.20)
0.080 (2.03)	80	0.063 (1.57)	0.100 (2.54)	0.160 (4.06)
0.100 (2.5)	100	0.080 (2.03)	0.126 (3.20)	0.200 (5.08)
0.120 (3.05)	120	0.100 (2.54)	0.160 (4.06)	0.250 (6.35)
0.140 (3.56)	140	0.126 (3.20)	0.200 (5.08)	0.320 (8.13)
0.160 (4.06)	160	0.160 (4.06)	0.250 (6.35)	
0.200 (5.08)	200	0.200 (5.08)	0.320 (8.13)	
0.240 (6.10)	240	0.250 (6.35)		
0.280 (7.11)	280	0.320 (8.13)		

bronze of higher lead content since leaded bronze increases in attenuation with increase in lead content. This would be equivalent to using a lower group IQI.

NOTE 1 — In developing the eight listed materials groups, a number of other trade names or other nominal alloy designations were evaluated. For the purpose of making this practice as useful as possible, these materials are listed and categorized, by group, as follows:

(1) *Group 2* — Haynes Alloy IN-100.

(2) *Group 3* — Haynes Alloy No. 713C, Hastelloy D, G. E. Alloy SEL, Haynes Stellite Alloy No. 21, GMR-235 Alloy, Haynes Alloy No. 93, Inconel X, Inconel 718, and Haynes Stellite Alloy No. S-816.

(3) *Group 4* — Hastelloy Alloy F, Hastelloy Alloy X, and Multimeter Alloy Rene 41.

(4) *Group 5* — Alloys in order of increasing attenuation: Hastelloy Alloy B, Hastelloy Alloy C, Haynes Stellite Alloy No. 31, Thetaloy, Haynes Stellite No. 3, Haynes Alloy No. 25. Image quality indicators (IQIs) of any of these materials are considered applicable for the materials that follow it.

NOTE 2 — The committee formulating these recommendations recommends other materials may be added to the materials groups listed as the need arises or as more information is gained, or that additional materials groups may be added.

7.3 Method for Other Materials:

7.3.1 For materials not herein covered, IQIs of the same materials, or any other material, may be used if the following requirements are met. Two blocks of equal thickness, one of the material to be examined (production material) and one of the IQI material, shall be radiographed on one film by one exposure at the lowest energy level to be used for production. Transmission densitometer measurements of the radiographic image of each material shall be made. The density of each image shall be between 2.0 and 4.0. If the image density of the IQI material is within 1.00 to 1.15 times (−0% to +15%) the image density of the production material, IQIs made of that IQI material may be used in radiography of that production material. The percentage figure is based on the radiographic density of the IQI material.

7.3.2 It shall always be permissible to use IQIs of similar composition as the material being examined.

8. Image Quality Indicator (IQI) Certification

8.1 Documents shall be provided by the IQI manufacturer attesting to the following:

8.1.1 IQI identification alternate, if used.

8.1.2 Material type.

8.1.3 Conformance to specified tolerances for dimensional values.

8.1.4 ASTM standard designation, for example, ASTM E 747 — (year designation) used for manufacturing.

9. Precision and Bias

9.1 *Precision and Bias* — No statement is made about the precision or bias for indicating the quality of images since the results merely state whether there is conformance to the criteria for success specified in this practice.

10. Keywords

10.1 density; image quality level; IQI; radiologic; radiology; x-ray and gamma radiation

ANNEX

(Mandatory Information)

A1. ALTERNATE IQI IDENTIFICATION

A1.1 The use of IQIs with identifications as shown in Figs. A1.1 through A1.9 and as listed in Table A1.1 is permitted as an acceptable alternate provided all other requirements of Practice E 747 are satisfied.

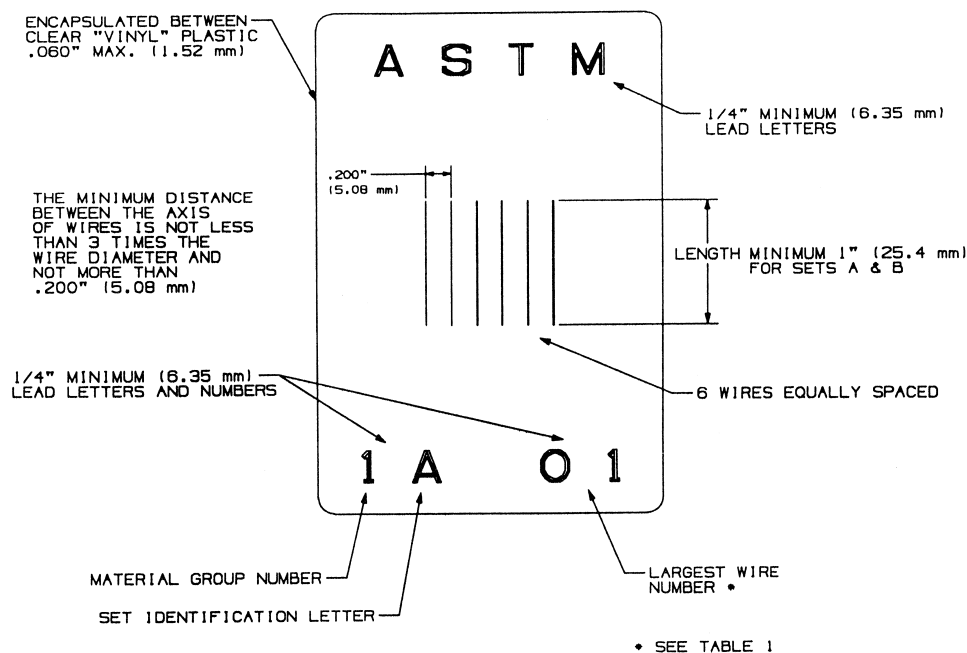
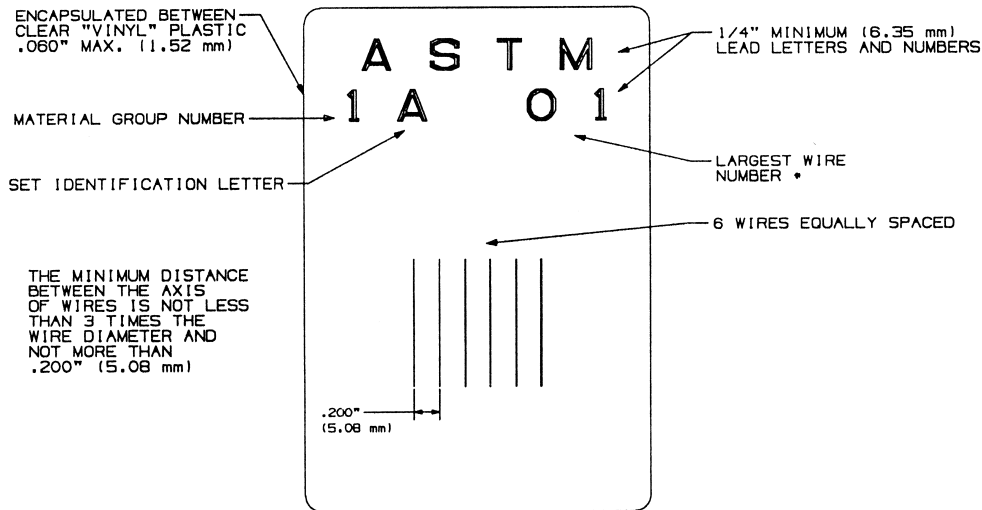
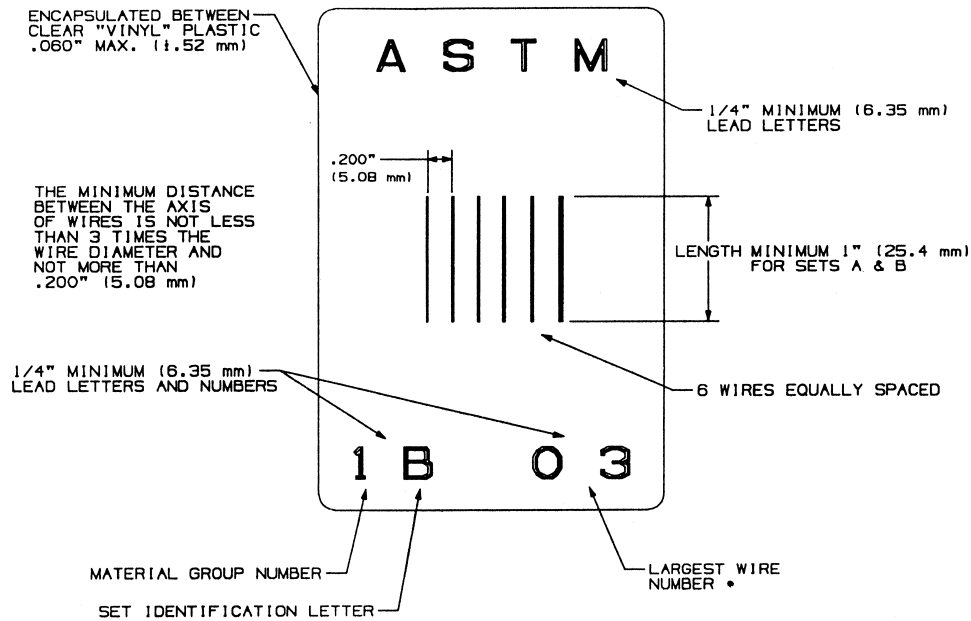


FIG. A1.1 SET A/ALTERNATE 1



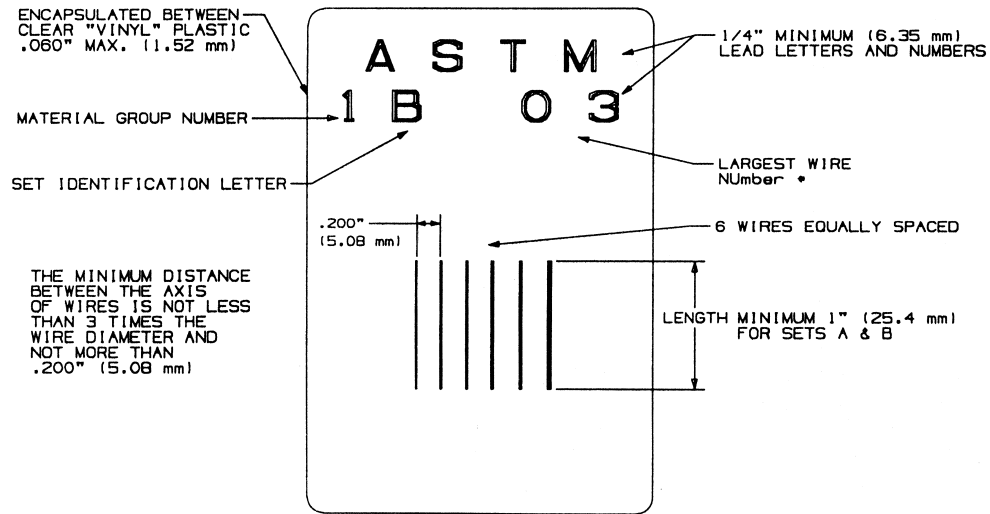
• SEE TABLE 1

FIG. A1.2 SET A/ALTERNATE 2



• SEE TABLE 1 FOR ACTUAL VALUE

FIG. A1.3 SET B/ALTERNATE 1



• SEE TABLE 1 FOR ACTUAL VALUE

FIG. A1.4 SET B/ALTERNATE 2

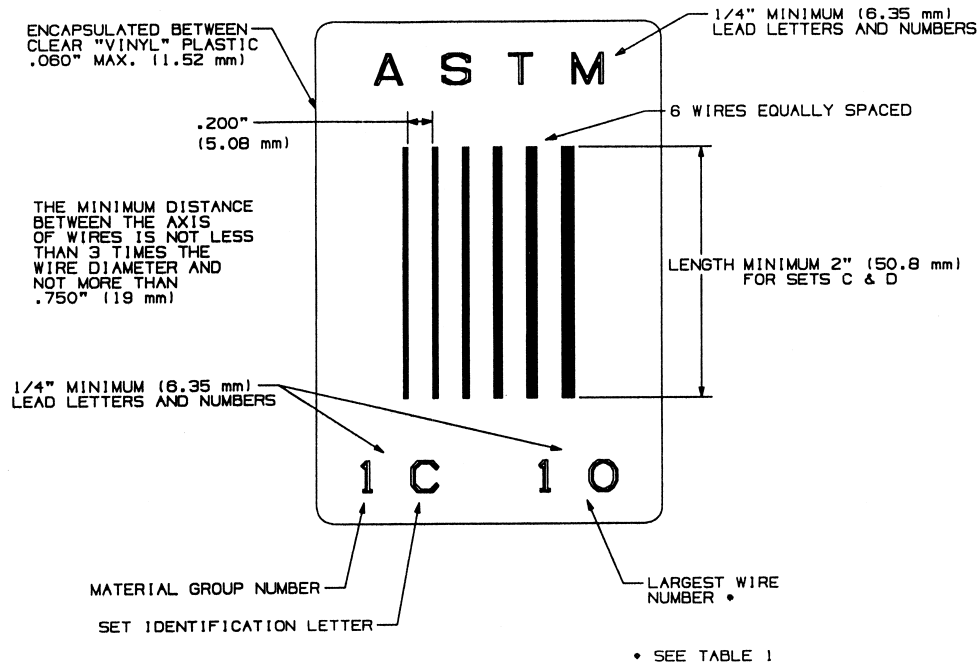


FIG. A1.5 SET C/ALTERNATE 1

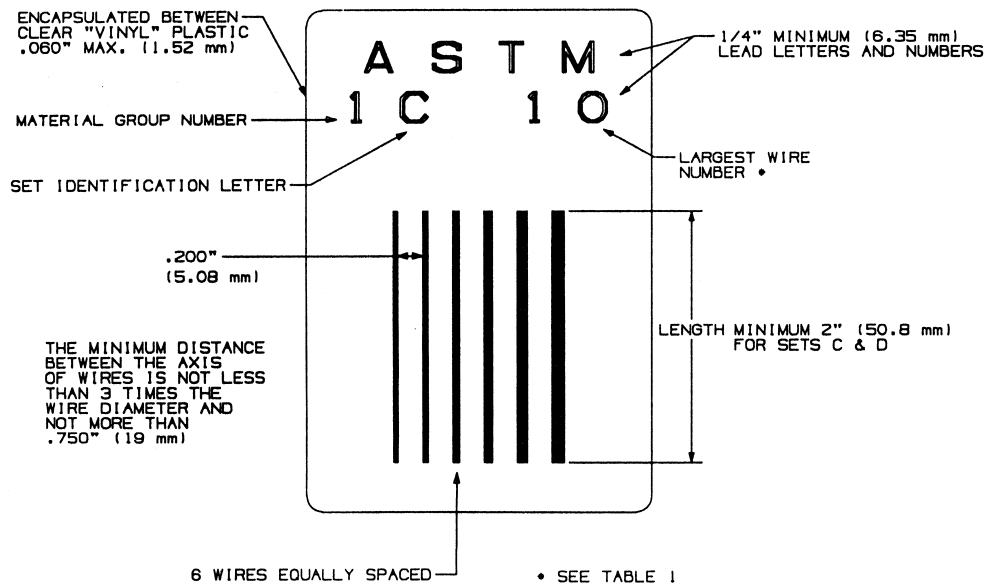


FIG. A1.6 SET C/ALTERNATE 2

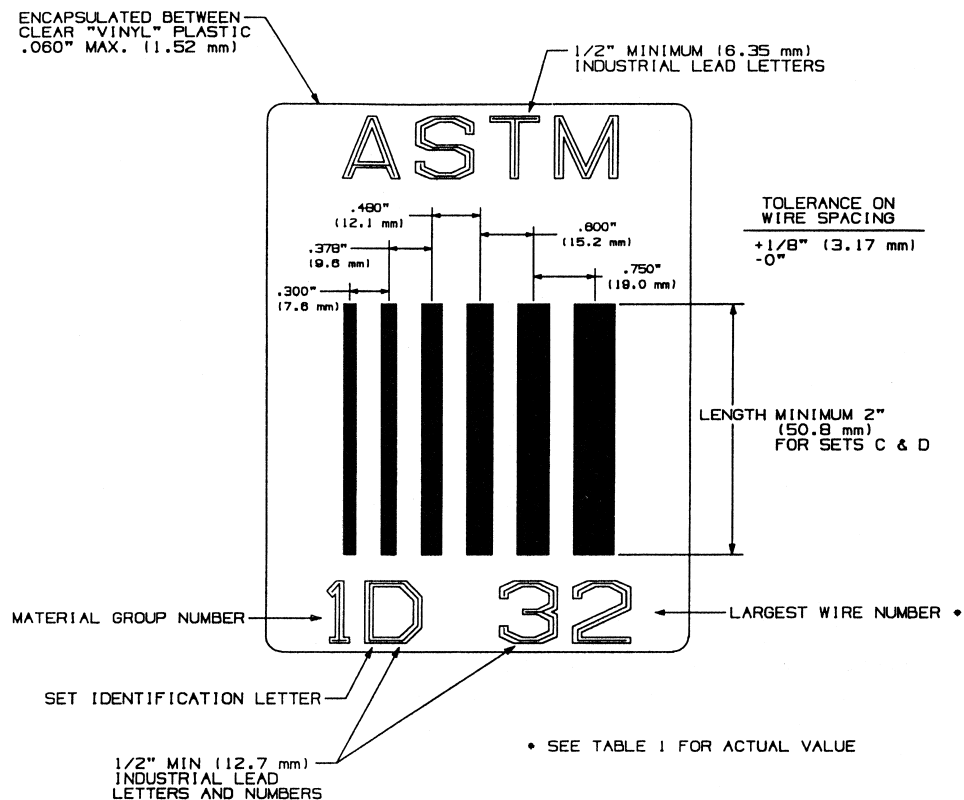


FIG. A1.7 SET D/ALTERNATE 1

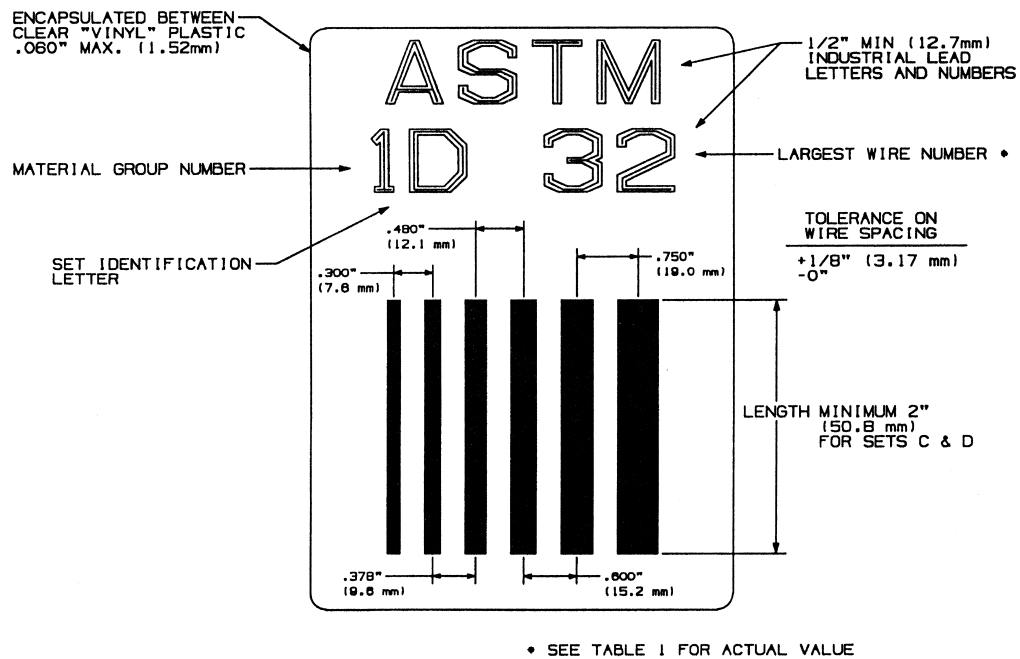
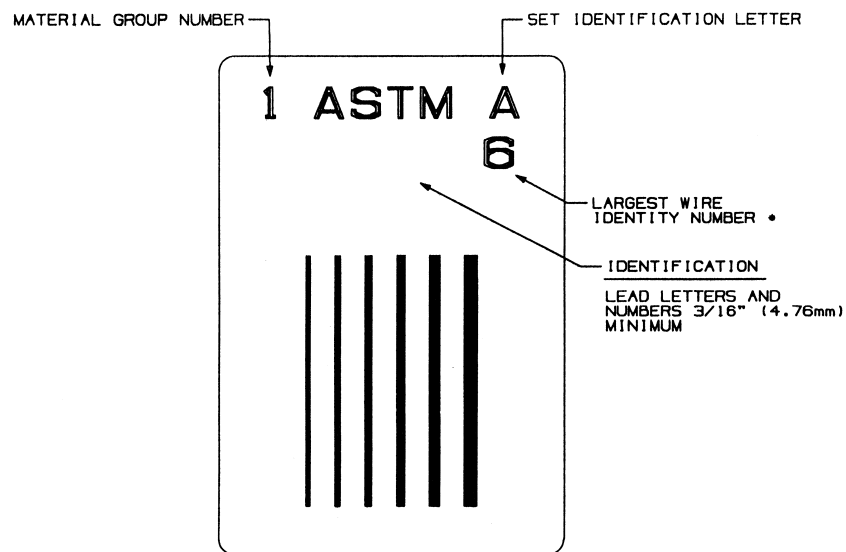


FIG. A1.8 SET D/ALTERNATE 2



* SEE TABLE 1

NOTE—All other IQI requirements as shown on Figs. 1 through 8 or Figs. A1.1 through A1.8 apply.

FIG. A1.9 ALTERNATE IDENTIFICATION LOCATIONS AND LETTER, NUMBER SIZE-TYPICAL ALL SETS (A, B, C, D)

TABLE A1.1
PENETRATOR SIZES WIRE DIAMETER, in. (mm)

SET A	SET B
0.0032 (0.08) ⁴	0.010 (0.25)
0.004 (0.1)	0.013 (0.33)
0.005 (0.13)	0.016 (0.41)
0.0063 (0.16)	0.020 (0.51)
0.008 (0.2)	0.025 (0.64)
0.010 (0.25)	0.032 (0.81)
SET C	SET D
0.032 (0.81)	0.100 (2.5)
0.040 (1.02)	0.126 (3.2)
0.050 (1.27)	0.160 (4.06)
0.063 (1.6)	0.20 (5.1)
0.080 (2.03)	0.25 (6.4)
0.100 (2.5)	0.32 (0.81)

⁴ The 0.0032 wire may be used to establish a special quality level as agreed upon between the purchaser and the supplier.

APPENDIX**(Nonmandatory Information)****X1. CALCULATING OTHER EQUIVALENTS**

X1.1 The equation to determine the equivalencies between wire and (hole type) IQIs is as follows:

$$F^3 d^3 l = T^2 H^2 (\pi/4)$$

where:

F = form factor for wire, 0.79,

d = wire diameter, in. (mm),

l = effective length of wire, 0.3 in. (7.6 mm),

T = plaque thickness, in. (mm), and

H = diameter of hole, in. (mm).

X1.2 It should be noted that the wire and plaque (hole type) IQI sensitivities cannot be related by a fixed constant.

X1.3 Figures X1.1 and X1.2 are conversion charts for hole type IQI's containing 1T and 2T holes to wires. The sensitivities are given as a percentage of the specimen thickness.

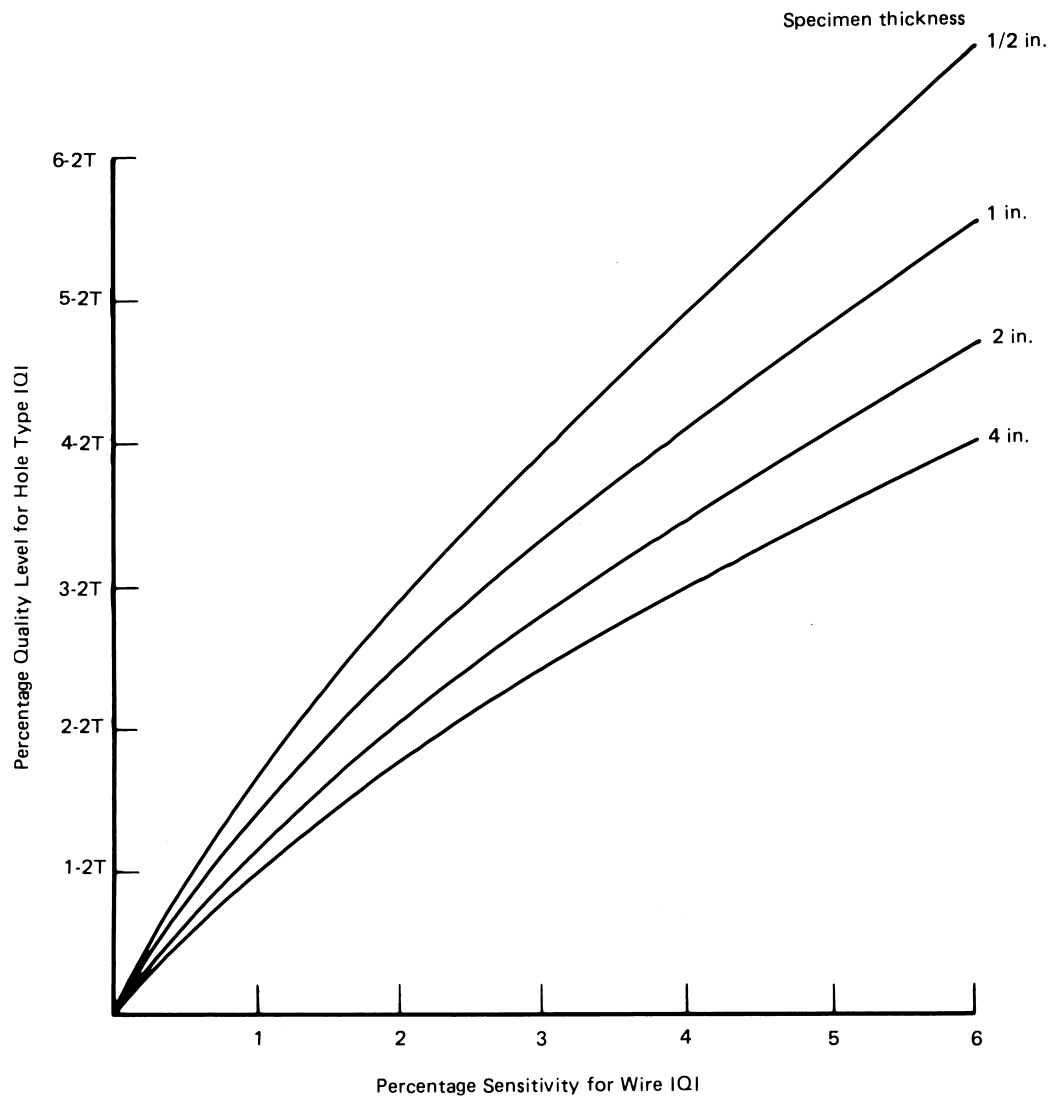


FIG. X1.1 CONVERSION CHART FOR 2-T QUALITY LEVEL HOLES TO PERCENTAGE WIRE SENSITIVITY

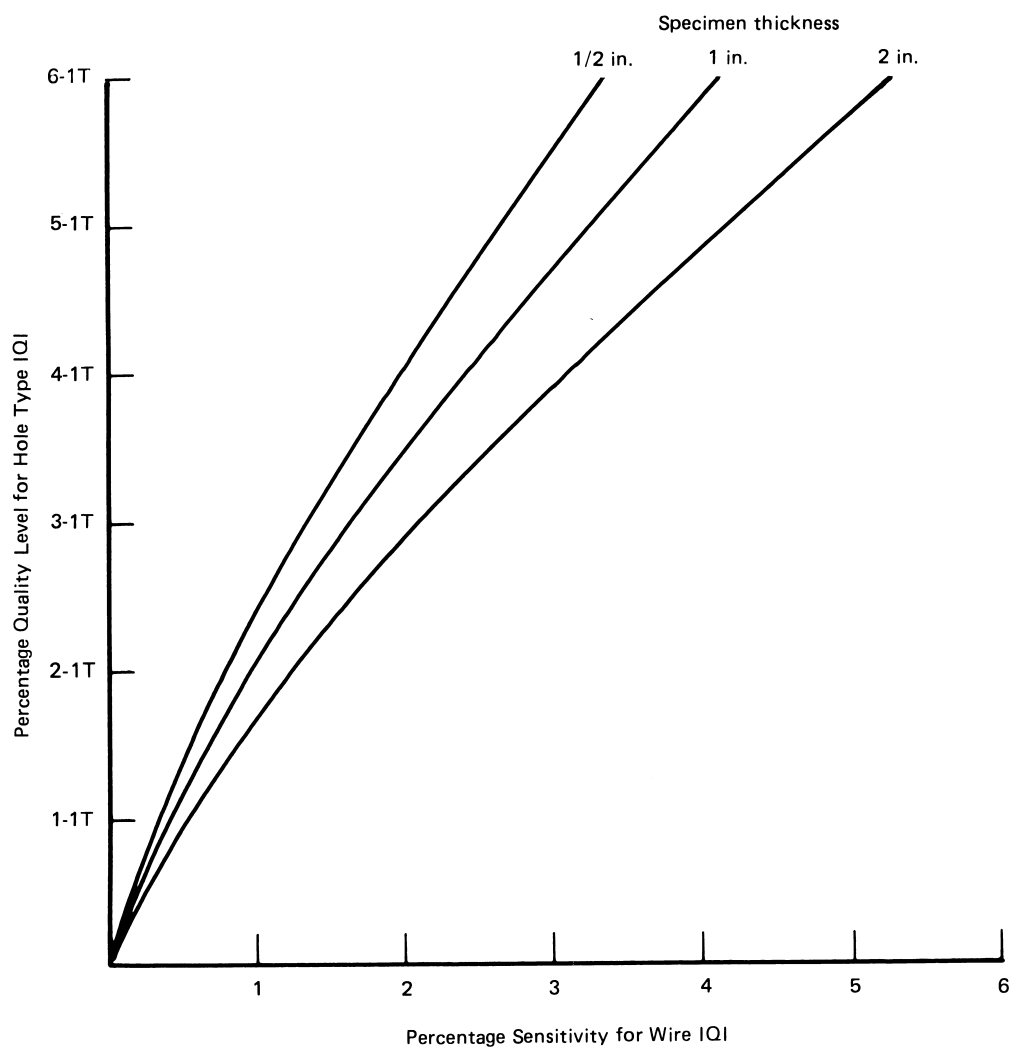


FIG. X1.2 CONVERSION CHART FOR 1-T QUALITY LEVEL HOLES TO PERCENTAGE WIRE SENSITIVITY

STANDARD GUIDE FOR CONTROLLING THE QUALITY OF INDUSTRIAL RADIOGRAPHIC FILM PROCESSING



SE-999



(Identical with ASTM Specification E 999-95)

1. Scope

1.1 This guide establishes guidelines that may be used for the control and maintenance of industrial radiographic film processing equipment and materials. Effective use of these guidelines aid in controlling the consistency and quality of industrial radiographic film processing.

1.2 Use of this guide is limited to the processing of films for industrial radiography. This guide includes procedures for wet-chemical processes and dry processing techniques.

1.3 The necessity of applying specific control procedures such as those described in this guide is dependent, to a certain extent, on the degree to which a facility adheres to good processing practices as a matter of routine procedure.

1.4 If a nondestructive testing agency, as described in Practice E 543, is used to perform the examination, the testing agency shall meet the requirements of Practice E 543.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. For more specific safety precautionary statements, see 4.2.3, 4.3.1, 6.1.2, and 6.1.9.*

2. Referenced Documents

2.1 ASTM Standard:

- E 94 Guide for Radiographic Testing
- E 543 Practice for Determining the Qualification of Non-destructive Testing Agencies
- E 1316 Terminology for Nondestructive Examinations

2.2 ANSI Standard:

- ANSI PH 4.8 Methylene Blue Method for Measuring Thiosulfate and Silver Densitometric Method for Measuring Residual Chemicals in Films, Plates, and Papers

3. Terminology

3.1 Definitions — For definitions of terms used in this guide, see Terminology E 1316.

4. Significance and Use

4.1 The provisions in this guide are intended to control the reliability or quality of the image development process only and are not intended for controlling the acceptability or quality of industrial radiographic films or of the materials or products radiographed. It is further intended that this guide be used as an adjunct to and not a replacement for Guide E 94.

5. Chemical Mixing for Manual and Automatic Processes

5.1 Any equipment that comes in contact with processing solutions should be made of glass, hard rubber, polyethylene, PVC, enameled steel, stainless steel, or

other chemically inert materials. This includes materials such as plumbing, mixing impellers, and the cores of filter cartridges. Do not allow materials such as tin, copper, steel, brass, aluminum, or zinc to come into contact with processing solutions. These materials can cause solution contamination that may result in film fogging or rapid oxidation.

5.2 *Mixing Chemicals:*

5.2.1 Do not mix powdered chemicals in processor tanks, since undissolved particles may be left in the square corners of the tank. Mix solutions in separate containers made from materials specified in 4.1.

5.2.2 Carefully follow the manufacturer's package directions or formulas for mixing the chemicals. Start with the correct volume of water at the temperature specified in the instructions, and add chemicals in the order listed.

5.2.3 Caution — During the mixing and use of photographic processing chemicals, be sure to observe all precautionary information on chemical containers and in instructions.

5.3 *Contamination of Solutions:*

5.3.1 Thoroughly clean all mixing equipment immediately after use to avoid contamination when the next solution is mixed. When mixing fixer from powder, make sure to add the powder carefully to the water in the mixing tank so that fixer dust does not get into other processing solutions. When mixing any chemical, protect nearby tank solutions with floating lids and dust covers. The use of a vent hood is recommended as a safety precaution.

5.3.2 The water supply should either be distilled or filtered so that it is clean and sediment-free.

5.3.3 If large tanks are used for mixing, carefully mark the volume levels to be certain that volumes are correct.

5.3.4 Use of impeller-type mixers provides rapid, thorough mixing but take care to position the impeller at such an angle and depth that the minimum amount of air will be drawn into the solution. Over-mixing of the solutions can cause oxidation, especially with developers, and should be avoided. Rinse the shaft, impeller, and mounting clamp with water after use.

5.4 *Maintaining Equipment:*

5.4.1 Immediately clean all mixing equipment after use.

5.4.2 In addition to cleaning equipment immediately after use, wash any mixing apparatus that has been idle for a long period of time to eliminate dust and dirt that may have accumulated.

5.4.3 Processing hangers and tanks should be free of corrosion and chemical deposits. Encrusted deposits that accumulate in tanks, trays, and processing equipment and that are difficult to remove by conventional cleaning can be removed by using the specially formulated cleaning agents recommended by the chemical or equipment manufacturer.

6. *Storage of Solutions*

6.1 In Original Containers — Follow the manufacturer's storage and capacity recommendations packaged with the chemicals. Do not use chemicals that have been stored longer than recommended.

6.2 In Replenisher or Process Tanks — Wherever possible, protect solutions in tanks with floating lids and dust covers. In addition to preventing contaminants from entering solutions, floating lids and dust covers help to minimize oxidation and evaporation from the surface of the solutions. Evaporation can concentrate solutions and reduce temperatures causing precipitation of some of the solution constituents.

6.2.1 Store replenisher solutions for small volume operations in airtight containers. The caps of these containers should be free of corrosion and foreign particles that could prevent a tight fit.

6.3 Temperature — Store all solutions at normal room temperature, between 40 to 80°F (4 to 27°C). Storing solutions, particularly developer, at elevated temperatures can produce rapid oxidation resulting in loss of activity and a tendency to stain the film. Storage at too low a temperature can cause some solution to crystallize, and the crystals may not redissolve even with heating and stirring.

6.4 Deterioration — Photographic chemicals can deteriorate either with age or with usage. Carefully follow the manufacturer's recommendations for storage life and useful capacity. Discard processing solutions when the recommended number of films have been processed or the recommended storage life of the prepared solution has been reached, whichever occurs first.

6.5 Contamination:

6.5.1 Liquid chemicals are provided in containers with tight-fitting tops. To avoid contamination, never interchange the top of one container with another.

6.5.2 Clearly label replenisher storage tanks with the solution that they contain and use that container only with that solution. If more than one developer or one fixer formulation are being used, a separate replenisher tank should be dedicated to each chemical. Differences in developer or fixer formulations from one manufacturer to another may contaminate similar solutions.

7. Processing

7.1 Manual Processing:

7.1.1 Follow the temperature recommendations from the film or solution manufacturer and check thermometers. Check thermometers and temperature-controlling devices periodically to be sure that the process temperatures are correct. Process temperatures should be checked at least once per shift. Keep the temperature of the stop (if used), fixer, and wash water within $\pm 5^{\circ}\text{F}$ ($\pm 3^{\circ}\text{C}$) of the developer temperature.

7.1.2 Caution — An unprotected mercury-filled thermometer should never be used for photographic processing applications because accidental breakage could result in serious mercury contamination of the process.

7.1.3 Control of processing solution temperature and immersion time relationships are instrumental considerations when establishing a processing procedure that will consistently produce radiographs of desired density and quality. The actual time and temperature relationships established are governed largely by the industrial radiographic films and chemicals used and should be within the limits of the manufacturer's recommendations for those materials. When determining the immersion time for each solution, assure that the draining time is included. Draining time should be consistent from solution to solution. The darkroom timers used should be periodically checked for accuracy.

7.1.4 Agitate at specified intervals for the times recommended by the film or solution manufacturer.

7.1.5 During film processing certain constituents within the solutions undergo chemical transformations that render them useless for further processing functions. In addition, some solution adheres to the film and is carried on into the next solution during processing. In

order to compensate for these reductions in solution activity and volume, add replenishment solution. The volume of replenishment necessary is governed primarily by the number, size, and density of films processed. Manufacturer's recommendations for replenishment are based on these criteria and will generally provide suitable results for the expected life of the solution. In any case, maintain solution levels to ensure complete immersion of the film.

7.1.6 The functional constituents in a freshly mixed developer solution tend to overreact on the initial films processed and may develop unexposed areas on the films. For this reason, measures should be taken to stabilize the activity of the solution and thus *season* the developer. This can be accomplished by the use of developer starter solution or by processing a series of *seasoning films* (see Note 1) in the freshly mixed solution. When using developer starter solution follow the manufacturer's recommendations for the product. When using seasoning films expose the films with visible light and then develop these films in the solution to be seasoned. Use three 14 by 17-in. (35 by 43-cm) films, or equivalent, per gallon (3.8 L) of developer.

NOTE 1 — Seasoning films may be new films or films that may not be generally suitable for production purposes due to excessive gross fog (base plus fog) density, expiration of shelf life, or other reasons.

7.1.7 Handle all films carefully during the processing cycle and allow adequate time for the film to sufficiently drain before transferring it to the next solution. The use of a stop bath or clear water rinse between developing and fixing may also be appropriate. The stop bath or clear water rinse serves to arrest development and also aids in minimizing the amount of developer carried over into the fixer solution. Insufficient bath-to-bath drain time may cause excessive solution carry-over which can contaminate and shorten the life of solutions in addition to causing undesirable effects on processed radiographs.

7.1.8 When washing films, a wetting agent may be appropriate to use to prevent water spots and streaking during drying.

7.1.9 Caution — Prior to placing films in the dryer, ensure that the dryer is clean and that adequate heat and ventilation are provided. During drying, visually examine the films to determine the length of time required for sufficient drying.

7.2 Automated Processing:

7.2.1 Immersion time and solution temperature relationships can be more closely controlled with automatic processing since the equipment provides external gages for monitoring purposes. As a general guideline, follow the manufacturer's recommendations for industrial processing materials. However, the actual procedure used should be based on the variables encountered by the user and his particular needs. Check solution temperatures daily with a thermometer to ensure that the processor's thermometers are accurate [$\pm 1^{\circ}\text{F}$ (0.5°C)].

7.2.2 Check the machine speed by measuring the time it takes for a given length of film to pass a specific point. (For example, if the indicated machine speed is 2 ft/min, place two marks on a length of film 1 ft apart. The second mark should pass a specific location, such as the entrance to the processor, exactly 30 s after the first mark has passed the same point.) An optional method for measuring processor speed is to install a tachometer on the main drive motor and determine desired RPM/processing speed relationships.

7.2.3 Agitation is provided by the action of the processor rollers, recirculation pumps, wash water flow, and no external agitation is needed.

7.2.4 For processors with replenishment systems, use the replenishment rates recommended by the film or solution manufacturer.

7.2.4.1 Accurate replenishment increases the useful life of solutions to a great extent by replacing ingredients that are depleted and maintains the process at a constant, efficient level.

7.2.4.2 Check replenishment systems at least daily to ensure that correct volumes are being injected into the solutions. For installations processing very large amounts of film (in excess of two tank turnovers of replenisher per week), checks on replenishment rates should be made more frequently. Processor manufacturer's recommendations will generally provide an adequate procedure for checking replenishment volumes.

7.2.5 For seasoning freshly mixed developer solution, refer to the provisions in 7.1.5.

7.2.6 Always fill the fixer tank first, following the manufacturer's instructions, then rinse and fill the developer tank. This minimizes the possibility of fixer accidentally splashing into the developer solution. When replacing or removing processor racks, always use a splash guard to further reduce the possibility of contamination.

7.2.7 Drying:

7.2.7.1 Make sure the dryer is clean and that no foreign material has settled on the rollers. Routinely examine the ventilation system to ensure that air paths are not blocked and that films are uniformly dried. The heat setting used for air temperature should be compatible with the film manufacturer's recommendations.

7.2.7.2 The dryer efficiency can be tested by processing six consecutive 14 by 17-in. (35 by 43-cm) production films, or equivalent, and examining them immediately after the drying cycle is complete. If damp or undried areas are observed, increase the dryer temperature. Should an increase in temperature not dry the film, retest the fixer activity.

7.3 Dry Processing:

7.3.1 Follow manufacturer's recommendations for thermal processor warm-up requirements.

7.3.2 Follow time-temperature recommendations from the manufacturer.

8. Activity Testing of Solutions for Manual and Automatic Processing

8.1 Developer — A suggested method of testing developer activity is by processing a production radiography with a known *aim* density in the area of interest, and then measuring the actual density in that area. The actual density should be within ± 0.15 log E units of the expected *aim* density.

NOTE 2 — The term *known aim density* refers to an area on a routinely radiographed part (such as a flange or a step wedge) whose thickness or composition is consistent. This area provides a *benchmark* density for the process, and can serve the function normally associated with a process control strip.

8.2 Fixer:

8.2.1 Fixer solution activity can be tested by determining the time required to remove the silver from an unexposed film. The film should be periodically agitated during processing. An active fixer solution should remove the silver (the cloudy appearance in the fixer bath should disappear) in approximately one-half of the time recommended for the process.

8.2.2 If physical examination shows unfixed spots or areas, the fixer should be discarded. Unfixed areas may appear as dull, nonreflective areas that may be yellowish in color depending on the actual lack of fixer activity.

8.3 Wash:

8.3.1 Proper washing is necessary to remove residual fixer from the film. If not removed from the film, these chemicals will cause subsequent damage (staining) and deterioration of the radiographic image, especially in low density areas.

8.3.2 The effectiveness of washing may be checked using the *residual processing chemicals* test described in Guide E 94 or ANSI PH 4.8.

8.3.3 If physical examination of the films after washing shows dirt or scum that was not present before washing, the wash tanks should be drained and cleaned. Drain wash tanks whenever they are not being used. In order to minimize washing artifacts it is recommended that *scavenger films* be processed at start up to clear out scum and foreign material; the use of algaecides is also recommended to retard the growth of organisms within the wash bath.

9. Records

9.1 Accurate records should be kept of the following items:

9.1.1 Brand name and model of processor, if used.

9.1.2 Brand names and batch number of chemicals used.

9.1.3 Time of development.

9.1.4 Temperature of processing chemicals.

9.1.5 Date new chemicals were placed in use.

9.1.6 Replenishment rates.

10. Maintenance

10.1 Maintenance schedules provided by the manufacturer for preventive maintenance should be adhered to in order to assure consistent chemical and mechanical operation as set forth by the manufacturer.

11. Keywords

11.1 automatic processing; film; manual processing; processing; radiographic; solutions

STANDARD PRACTICE FOR DESIGN, MANUFACTURE, AND MATERIAL GROUPING CLASSIFICATION OF HOLE-TYPE IMAGE QUALITY INDICATORS (IQI) USED FOR RADIOLOGY



SE-1025



(Identical with ASTM Specification E 1025-98)

1. Scope

1.1 This practice covers the design, material grouping classification, and manufacture of hole-type image quality indicators (IQI) used to indicate the quality of radiologic images.

1.2 This practice is applicable to X-ray and gamma-ray radiology.

1.3 The values stated in inch-pound units are to be regarded as standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

- B 139 Specification for Phosphor Bronze Rod, Bar, and Shapes
- B 150 Specification for Aluminum Bronze Rod, Bar, and Shapes
- B 161 Specification for Nickel Seamless Pipe and Tube
- B 164 Specification for Nickel-Copper Alloy Rod, Bar, and Wire
- B 166 Specification for Nickel-Chromium-Iron Alloys (UNS N06600, N06601, and N06690) and Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617) Rod, Bar, and Wire
- E 1316 Terminology for Nondestructive Examinations

3. Terminology

3.1 Definitions — The definitions of terms relating to gamma and x-radiology in Terminology E 1316, Section D, shall apply to the terms used in this practice.

4. Hole-Type IQI Requirements

4.1 Image quality indicators (IQIs) used to determine radiologic-image quality levels shall conform to the following requirements.

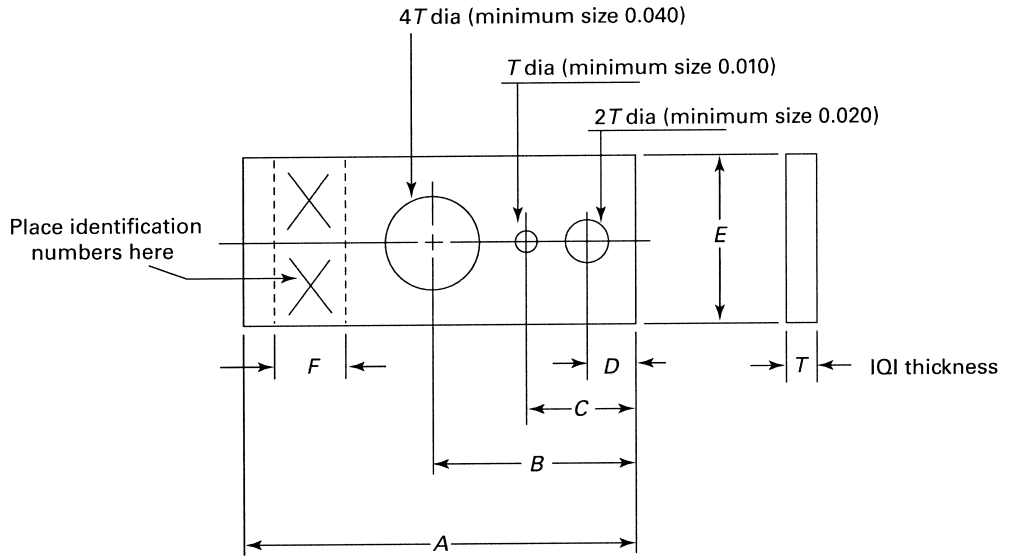
4.1.1 Standard Hole-Type IQIs:

4.1.1.1 Image quality indicators (IQIs) shall be fabricated from materials or alloys identified or listed in accordance with 7.3. Other materials may be used in accordance with 7.4.

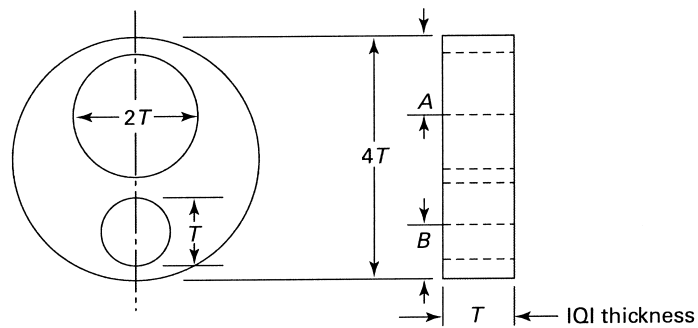
4.1.1.2 Image quality indicators (IQIs) shall dimensionally conform to the requirements of Fig. 1.

4.1.1.3 Both the rectangular and the circular IQI shall be identified with number(s) made of lead or a material of similar radiation opacity. The number shall be bonded to the rectangular IQIs and shall be placed adjacent to circular IQIs to provide identification of the IQI on the image. The identification numbers shall indicate the thickness of the IQI in thousandths of an inch, that is, a number 10 IQI is 0.010 in. thick, a number 100 IQI is 0.100 in. thick, etc. Additional identification requirements are provided in 7.2.

4.1.1.4 Alloy-group identification shall be in accordance with Fig. 2. Rectangular IQIs shall be



(a) Design for IQIs to and including 160



(b) Design for IQIs Over 160

Note 1 — All dimensions in inches (Note 6).

Note 2 — Tolerances for IQI thickness and hole diameter.

Note 3 — XX identification number equals T in 0.001 inches.

Note 4 — IQIs No. 1 through 9 are not $1T$, $2T$, and $4T$.

Note 5 — Holes shall be true and normal to the IQI. Do not chamfer.

Note 6 — To convert inch dimensions to metric, multiply by 25.4.

Identification Number T (Note 3)	A	B	C	D	E	F	Tolerances (Note 2)
1–4	1.500	0.750	0.438	0.250	0.500	0.250	$\pm 10\%$
	± 0.015	± 0.015	± 0.015	± 0.015	± 0.015	± 0.030	
5–20	1.500	0.750	0.438	0.250	0.500	0.250	± 0.0005
	± 0.015	± 0.015	± 0.015	± 0.015	± 0.015	± 0.030	
21–50	...	...	...	...	...	...	± 0.0025
Over 50–160	2.250	1.375	0.750	0.375	1.000	0.375	± 0.005
	± 0.030	± 0.030	± 0.030	± 0.030	± 0.030	± 0.030	
Over 160	1.330T	0.830T	...	...	...	...	± 0.010
	± 0.005	± 0.005					

FIG. 1 IQI DESIGN

notched. Image quality indicators (IQIs) shall be vibro-tooled or etched as specified.

4.1.2 Modified Hole-Type IQI:

4.1.2.1 The rectangular IQI may be modified in length and width as necessary for special applications, provided the hole size(s) and IQI thickness conform to Fig. 1.

4.1.2.2 The IQIs shall be identified as specified in 4.1.1.3, except that the identification numbers may be placed adjacent to the IQI if placement on the IQI is impractical.

4.1.2.3 When modified IQIs are used, details of the modification shall be documented in the records accompanying the examination results.

5. IQI Procurement

5.1 When selecting IQIs for procurement, the following factors should be considered:

5.1.1 Determine the alloy group(s) of the material to be examined.

5.1.2 Determine the thickness or thickness range of the material(s) to be examined.

5.1.3 Select the applicable IQIs that represent the required IQI thickness and alloy(s).

NOTE 1 — This practice does not recommend or suggest specific IQI sets to be procured. Section 5 is an aid in selecting IQIs based on specific needs.

6. Image Quality Levels

6.1 Image quality levels are designated by a two part expression X - YT . The first part of the expression X refers to the IQI thickness expressed as a percentage of the specimen thickness. The second part of the expression YT refers to the diameter of the hole and is expressed as a multiple of the IQI thickness, T . The image quality level 2- $2T$ means that the IQI thickness T is 2% of the specimen thickness and that the diameter of the IQI imaged hole is $2 \times$ the IQI thickness.

NOTE 2 — Image Quality Indicators (IQIs) less than number 10 have hole sizes 0.010, 0.020, and 0.040 in. diameter regardless of the IQI thickness. Therefore, IQIs less than number 10 do not

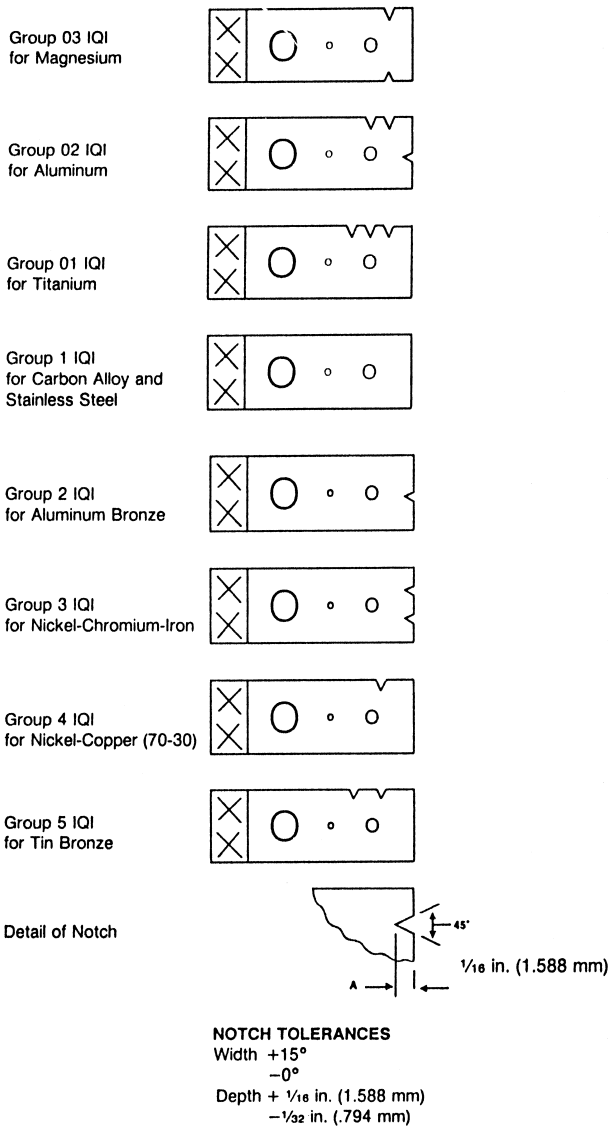


FIG. 2 RECTANGULAR IQI NOTCH IDENTIFICATION AND MATERIAL GROUPING

TABLE 1
TYPICAL IMAGE QUALITY LEVELS

Standard Image Quality Levels			
		Minimum Perceptible	
Image Quality Levels		Hole Diameter	Equivalent IQI Sensitivity, % ^B
Levels	IQI Thickness		
2-1 T	1/50 (2%) of Specimen Thickness	1 T	1.4
2-2 T ^A		2 T	2.0
2-4 T		4 T	2.8
Special Image Quality Levels			
1-1 T	1/100 (1%) of Specimen Thickness	1 T	0.7
1-2 T		2 T	1
4-2 T	1/25 (4%) of Specimen Thickness	2 T	4

^AFor Level 2-2T Radiologic — The 2 T hole in an IQI, $\frac{1}{50}$ (2%) of the specimen thickness, is visible.

^BEquivalent IQI sensitivity is that thickness of the IQI, expressed as a percentage of the part thickness, in which the 2 T hole would be visible under the same conditions.

represent the quality levels specified in 6.1 and Table 1. The equivalent sensitivity can be computed from data furnished in Appendix X1.

6.2 Typical image quality level designations are shown in Table 1. The level of inspection specified should be based on service requirements of the product. Care should be taken in specifying image quality levels 2-1T, 1-1T, and 1-2T by first determining that these levels can be maintained in production.

6.3 In specifying image quality levels, the contract, purchase order, product specification, or drawing should state the proper two-part expression and clearly indicate the thickness of the metal to which the level refers. In place of a designated two-part expression, the IQI number and minimum discernible hole size shall be specified.

7. Material Groups

7.1 General:

7.1.1 Materials have been designated in eight groups based on their radiation absorption characteristics: Groups 03, 02, and 01 for light metals and Groups 1 through 5 for heavy metals.

7.1.2 The light metal groups, magnesium (Mg), aluminum (Al), and titanium (Ti), are identified 03, 02, and 01 respectively for their predominant alloying constituent. The materials are listed in order of increasing radiation absorption.

7.1.3 The heavy metal groups, steel, copper base, nickel base, and kindred alloys, are identified 1 through

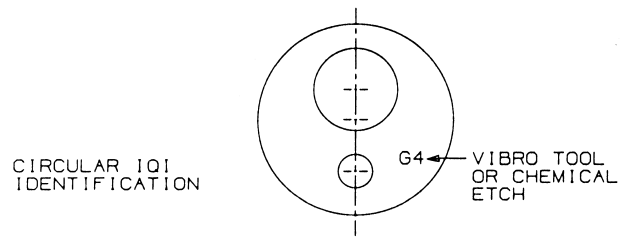


FIG. 3 CIRCULAR IQI IDENTIFICATION

5. The materials increase in radiation absorption with increasing numerical designation.

NOTE 3 — These groups were established experimentally at 180 kV on $\frac{3}{4}$ -in. (19-mm) thick specimens. They apply from 125 kV to the multivolt range.

7.1.4 Common trade names or alloy designations have been used for clarification of the pertinent materials.

7.1.5 The materials from which the IQI for the group are to be made are designated in each case, and these IQIs are applicable for all materials listed in that group. In addition, any group IQI may be used for any material with a higher group number, provided the applicable quality level is maintained.

7.2 Identification System:

7.2.1 A notching system has been designated for the eight groups of IQIs and is shown in Fig. 2.

7.2.2 For circular IQIs, a group designation shall be vibrotooled or chemically etched on the IQI to identify it by using the letter "G" followed by the group number, that is, G4 for a Group 4 IQI. For identification of the group on the image, corresponding lead characters shall be placed adjacent to the circular IQI, just as is done with the lead numbers identifying the thickness. The identification is shown in Fig. 3.

7.3 Materials Groups:

7.3.1 Materials Group 03:

7.3.1.1 Image quality indicators (IQIs) shall be made of magnesium or magnesium shall be the predominant alloying constituent.

7.3.1.2 Use on all alloys of which magnesium is the predominant alloying constituent.

7.3.2 Materials Group 02:

7.3.2.1 Image quality indicators (IQIs) shall be made of aluminum or aluminum shall be the predominant alloying constituent.

7.3.2.2 Use on all alloys of which aluminum is the predominant alloying constituent.

7.3.3 Materials Group 01:

7.3.3.1 Image quality indicators (IQIs) shall be made of titanium or titanium shall be the predominant alloying constituent.

7.3.3.2 Use on all alloys of which titanium is the predominant alloying constituent.

7.3.4 Materials Group 1:

7.3.4.1 Image quality indicators (IQIs) shall be made of carbon steel or Type 300 series stainless steel.

7.3.4.2 Use on all carbon steel, all low-alloy steels, all stainless steels, manganese-nickel-aluminum bronze (Superston).

7.3.5 Materials Group 2:

7.3.5.1 Image quality indicators (IQIs) shall be made of aluminum bronze (Alloy No. 623, of Specification B 150) or equivalent, or nickel-aluminum bronze (Alloy No. 630 of Specification B 150) or equivalent.

7.3.5.2 Use on all aluminum bronzes and all nickel-aluminum bronzes.

7.3.6 Materials Group 3:

7.3.6.1 Image quality indicators (IQIs) shall be made of nickel-chromium-iron alloy (UNS No. N06600) (Inconel). (See Specification B 166.)

7.3.6.2 Use on nickel-chromium-iron alloy and 18% nickel-maraging steel.

7.3.7 Materials Group 4:

7.3.7.1 Image quality indicators (IQIs) shall be made of 70 to 30 nickel-copper alloy (Monel) (Class A or B of Specification B 164) or equivalent, or 70 to 30 copper-nickel alloy (Alloy G of Specification B 161) or equivalent.

7.3.7.2 Use on nickel, copper, all nickel-copper series, or copper-nickel series of alloys, and all brasses (copper-zinc alloys). Group 4 IQIs may be used on the leaded brasses, since leaded brass increases in attenuation with increase in lead content. This would be equivalent to using a lower group IQI.

7.3.8 Materials Group 5:

7.3.8.1 Image quality indicators (IQIs) shall be made of tin bronze (Alloy D of Specification B 139).

7.3.8.2 Use on tin bronzes including gun-metal and valve bronze, leaded-tin bronze of higher lead content than valve bronze. Group 5 IQIs may be used on bronze of higher lead content since leaded bronze increases in attenuation with increase in lead content. This would be equivalent to using a lower group IQI.

NOTE 4 — In developing the eight listed materials groups, a number of other trade names or other nominal alloy designations were evaluated. For the purpose of making this practice as useful as possible, these materials are listed and categorized, by group, as follows:

- (1) *Group 2* — Haynes Alloy IN-100.
- (2) *Group 3* — Haynes Alloy No. 713C, Hastelloy D, G.E. Alloy SEL, Haynes Stellite Alloy No. 21, GMR-235 Alloy, Haynes Alloy No. 93, Inconel X, Inconel 718, and Haynes Stellite Alloy No. S-816.
- (3) *Group 4* — Hastelloy Alloy F, Hastelloy Alloy X, and Multimet Alloy Rene 41.
- (4) *Group 5* — Alloys in order of increasing attenuation: Hastelloy Alloy B, Hastelloy Alloy C, Haynes Stellite Alloy No. 31, Thetaloy, Haynes Stellite No. 3, Haynes Alloy No. 25. IQIs of any of these materials are considered applicable for the materials that follow it.

NOTE 5 — The committee formulating these recommendations recommended other materials may be added to the materials groups listed as the need arises or as more information is gained, or that additional materials groups may be added.

7.4 Radiographic Method for Other Materials:

7.4.1 For materials not herein covered, IQIs of the same materials, or any other material, may be used if the following requirements are met. Two blocks of equal thickness, one of the material to be examined (production material) and one of the IQI material, shall be radiographed on one film by one exposure at the lowest energy level to be used for production. Transmission densitometer readings for both materials shall be read from the film and shall be between 2.0 and 4.0 (radiographic) density for both materials. If the radiographic image density of the material from which the IQIs are to be fabricated is within +15 to -0% of the radiographic image density of the production material, the IQI material may be used to fabricate IQIs for examination of the production material. The percentage figure is based on the radiographic density of the IQI material.

7.4.2 It shall always be permissible to use IQIs of similar composition as the material being examined.

8. IQI Certification

8.1 Records shall be available that attest to the conformance of the material type, grouping (notches),

and dimensional tolerances of the IQIs specified by this practice.

of radiographs since the results merely state whether there is conformance to the criteria for success specified in this practice.

9. Precision and Bias

9.1 Precision and Bias — No statement is made about the precision or bias for indicating the quality

10. Keywords

10.1 density; image quality level; IQI; radiologic; radiology; X-ray and gamma radiation

APPENDIX

(Nonmandatory Information)

X1. EQUIVALENT IQI (PENETRAMEETER) SENSITIVITY (EPS)

X1.1 To find the equivalent IQI sensitivity (percent), the hole size (diameter in inches), of the IQI thickness (inches), for a section thickness (inches), the following computations may be used:

$$\alpha = \frac{100}{X} \sqrt{\frac{TH}{2}},$$

where:

α = equivalent IQI sensitivity, %,
 X = section thickness to be examined, in.,
 T = IQI thickness, in., and
 H = hole diameter, in.

X1.2 Alternate method for determining EPS using Fig. X1.1 Nomograph:

Example:

Given:

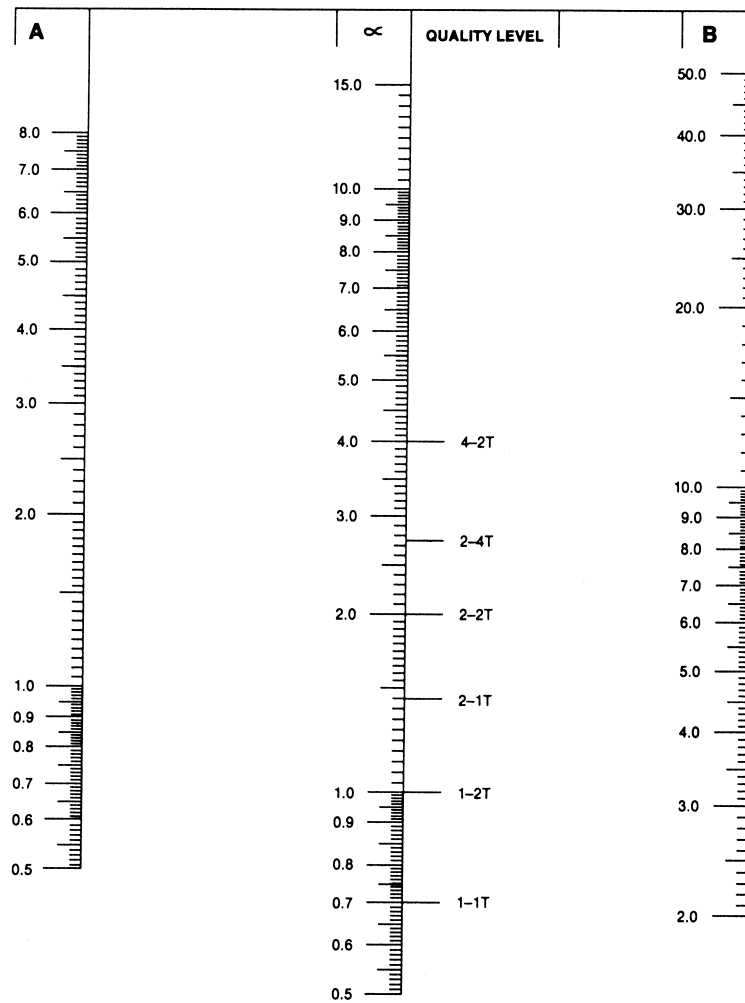
$X = 0.5$ in.
 $T = 0.005$ in., and
 $H = 0.0625$ in.

Solution:

$$A = \frac{100T}{X} = \frac{100 \times 0.005}{0.5} = 1.0\%$$

$$B = \frac{100H}{X} = \frac{100 \times 0.0625}{0.5} = 12.5\%$$

X1.3 Proceed to the nomograph (Fig. X1.1) and draw a line joining the 1.0% Value A and the 12.5% Value B and look on the center percent scale where the line crosses it and read the answer — 2.5%. Thus under the given conditions, equivalent IQI (penetrimeter) sensitivity (EPS) is 2.5%.



Definitions:

A equals the visible IQI (penetrator) plaque thickness (*T*) expressed as a percentage of the section (object) thickness to be radiographed in (inches).

B equals the diameter of the smallest IQI (penetrator) hole (*H*) for which the image is visibly expressed as a percentage of the section (object) thickness to be radiographed in (inches).

Note — The nomograph is used for computing equivalent IQI sensitivity from *T* (*T* equals penetrator thickness) inches and *H* (*H* equals hole diameter) inches. Draw a straight line joining the values on any two scales, and look on the third scale where the line crosses and read the answer. Due to normal reproduction methods in producing the nomograph, some small error (that is, less than 5%) may occur. If more accurate results are required, the formula in Appendix X1 should be used.

FIG. X1.1 EQUIVALENT IQI (PENETRATOR) SENSITIVITY NOMOGRAPH

STANDARD TEST METHOD FOR RADIOGRAPHIC EXAMINATION OF METALLIC CASTINGS



SE-1030



(Identical with ASTM Specification E 1030-95)

1. Scope

1.1 This test method provides a uniform procedure for radiographic examination of metallic castings using radiographic film as the recording medium.

1.2 Due to the many complex geometries and part configurations inherent with cast products, it is necessary to recognize potential limitations associated with obtaining complete radiographic coverage on castings. Radiography of areas where geometry or part configuration does not allow achievement of complete coverage with practical radiographic methods shall be subject to mutual agreements between purchaser and supplier. The use of alternative nondestructive methods for areas that are not conducive to practical radiography shall also be specifically agreed upon between purchaser and supplier.

1.3 The radiographic method is highly sensitive to volumetric discontinuities that displace a detectable volume of cast material. Discontinuities that do not displace an appreciable volume of material, however, such as cracks or other planar-type indications, may not be detected with radiography unless the radiation beam is coincidentally aligned with the planar orientation of the discontinuity. In view of this limitation, it may be considered appropriate to use the radiographic method in conjunction with additional nondestructive methods that maintain reliable detection capabilities for these types of discontinuities. The use of additional methods shall be specifically agreed upon between the purchaser and supplier.

1.4 The values stated in inch-pound units are to be regarded as standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use.*

It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards:

- E 94 Guide for Radiographic Testing
- E 142 Method for Controlling Quality of Radiographic Testing
- E 155 Reference Radiographs for Inspection of Aluminum and Magnesium Castings
- E 186 Reference Radiographs for Heavy-Walled [2 to 4½-in. (51 to 114-mm)] Steel Castings
- E 192 Reference Radiographs of Investment Steel Castings for Aerospace Applications
- E 272 Reference Radiographs for High-Strength Copper-Base and Nickel-Copper Alloy Castings
- E 280 Reference Radiographs for Heavy-Walled [4½ to 12-in. (114 to 305-mm)] Steel Castings
- E 310 Reference Radiographs for Tin Bronze Castings
- E 446 Reference Radiographs for Steel Castings Up to 2 in. (51 mm) in Thickness
- E 505 Reference Radiographs for Inspection of Aluminum and Magnesium Die Castings
- E 543 Practice for Evaluating Agencies that Perform Nondestructive Testing
- E 689 Reference Radiographs for Ductile Iron Castings
- E 746 Test Method for Determining Relative Image Quality Response of Industrial Radiographic Film
- E 747 Practice for the Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used For Radiology
- E 802 Reference Radiographs for Gray Iron Castings Up to 4½ in. (114 mm) in Thickness

- E 999 Guide for Controlling the Quality of Industrial Radiographic Film Processing
- E 1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology
- E 1254 Guide for Storage of Radiographs and Unexposed Industrial Radiographic Film
- E 1316 Terminology for Nondestructive Examination

2.2 ASNT/ANSI Standards:

- Recommended Practice No. SNT-TC-1A "Personnel Qualification and Certification in Nondestructive Testing"
- CP-189 Qualification and Certification of Nondestructive Testing Personnel

2.3 Military Standard:

- MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification

3. Terminology

3.1 Definitions — For definitions of terms used in this test method, see Terminology E 1316.

4. Significance and Use

4.1 The requirements expressed in this test method are intended to control the quality of the radiographic images, to produce satisfactory and consistent results, and are not intended for controlling the acceptability or quality of materials or products.

5. Basis of Application

5.1 The following items shall be agreed upon by the purchaser and supplier:

5.1.1 Nondestructive Testing Agency Evaluation — If specified in the contractual agreement, nondestructive testing (NDT) agencies shall be qualified and evaluated in accordance with Practice E 543. The applicable version of Practice E 543 shall be specified in the contractual agreement.

5.1.2 Personnel Qualification — NDT personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, MIL-STD-410 or a similar document. The practice or standard used and its applicable revision shall be specified in the contractual agreement between the using parties.

5.1.3 Requirements — General requirements (see 8.1, 8.2, 8.5, and 8.7.4) shall be specified.

5.1.4 Procedure Requirements (see 9.1, 9.1.1, 9.3, and 9.7.7) shall be specified.

5.1.5 Records — Record retention (see 12.1) shall be specified.

6. Apparatus

6.1 Radiation Sources:

6.1.1 X Radiation Sources — Selection of appropriate X-ray voltage and current levels is dependent upon variables regarding the specimen being examined (material type and thickness) and economically permissible exposure time. The suitability of these X-ray parameters shall be demonstrated by attainment of required penetrameter (IQI) sensitivity and compliance with all other requirements stipulated herein. Guide E 94 contains provisions concerning exposure calculations and charts for the use of X-ray sources.

6.1.2 Gamma Radiation Sources — Isotope sources, when used, shall be capable of demonstrating the required radiographic sensitivity.

6.2 Film Holders and Cassettes — Film holders and cassettes shall be light-tight and shall be handled properly to reduce the likelihood that they may be damaged. They may be flexible vinyl, plastic, or any durable material; or, they may be made from metallic materials. In the event that light leaks into the film holder and produces images on the film extending into the area of interest, the film shall be rejected. If the film holder exhibits light leaks, it shall be repaired before reuse or discarded. Film holders and cassettes should be routinely examined to minimize the likelihood of light leaks.

6.3 Intensifying Screens:

6.3.1 Lead-Foil Screens:

6.3.1.1 Intensifying screens of the lead-foil type are generally used for all production radiography. Lead-foil screens shall be of the same approximate area dimensions as the film being used and they shall be in direct contact with the film during exposure.

6.3.1.2 For X-ray voltages between 200 kV and 1 MeV, front and rear screen thicknesses shall be a minimum of 0.005 in. (0.13 mm) thick. Below 200 kV, front screen thicknesses up to 0.005 in. (0.13 mm) and rear screen thicknesses of at least 0.005 in. (0.13 mm) should be used if they improve radiographic quality. For isotope and high-voltage X-radiography (greater than 1 MeV) increased thicknesses may be

appropriate for improvements in radiographic quality and should be used accordingly. Intermediate screens (between multiloaded film) may be used if desired.

6.3.1.3 Sheet lead, with or without backing, used for screens should be visually examined for dust, dirt, oxidation, cracking or creasing, foreign material or other conditions that could render undesirable nonrelevant images on the film.

6.3.1 *Fluorescent or Fluorometallic Screens:*

6.3.2.1 Fluorescent or fluorometallic screen may be used. However, they must be capable of demonstrating the required penetrameter (IQI) sensitivity.

6.3.2.2 *Screen Care* — All screens should be handled carefully to avoid dents, scratches, grease, or dirt on active surfaces. Screens that render false indications on radiographs shall be discarded or reworked to eliminate the artifact.

6.4 *Filters* — Filters shall be used whenever the contrast reductions caused by low-energy scattered radiation or the extent of undercut and edge burn-off occurring on production radiographs is of significant magnitude so as to cause failure to meet the quality level or radiographic coverage requirements stipulated by the job order or contract (see Guide E 94).

6.5 *Masking* — Masking material may be used, as necessary, to help reduce image degradation due to undercutting (see Guide E 94).

6.6 *Penetrameters (IQI)* — Unless otherwise specified by the applicable job order or contract, only those penetrameters that comply with the design and identification requirements specified in Practice E 747 or Practice E 1025 shall be used.

6.7 *Shims and Separate Blocks* — Shims or separate blocks made of the same or radiographically similar materials (as defined in Method E 142) may be used to facilitate penetrameter positioning. There is no restriction on shim or separate block thickness provided the penetrameter and area-of-interest density tolerance requirements of 9.7.6.2 are met.

6.8 *Radiographic Location and Identification Markers* — Lead numbers and letters are used to designate the part number and location number. The size and thickness of the markers shall depend on the ability of the radiographic technique to image the markers on the radiograph. As a general rule, markers $\frac{1}{16}$ in. (1.58 mm) thick will suffice for most low energy (less than 1 MeV) X-ray and Iridium-192 radiography; for higher

energy radiography it may be necessary to use markers that are $\frac{1}{8}$ in. (3.17 mm) or more thick.

6.9 *Radiographic Density Measurement Apparatus* — Either a transmission densitometer or a step-wedge comparison film shall be used for judging film density requirements. Step wedge comparison films or densitometer calibration, or both, shall be verified by comparison with a calibrated step-wedge film traceable to the National Institute of Standards and Technology.

7. Reagents and Materials

7.1 *Films* — Definite rules on selection of films cannot be given since choice depends on such factors as the required radiographic quality level and the maximum economically permissible exposure time. In any case, the films selected must be capable of demonstrating the required penetrameter (IQI) sensitivity.

NOTE — Test Method E 746 provides a method for determining the relative image quality response of industrial radiographic film and may be used as the basis for film selection.

8. Requirements

8.1 *Procedure Requirement* — Unless otherwise specified by the applicable job order or contract, radiographic examination shall be performed in accordance with a written procedure. Specific requirements regarding the preparation and approval of written procedures shall be dictated by a purchaser and supplier agreement. The procedure details should include at least those items stipulated in Appendix X1. In addition, a radiographic standard shooting sketch (RSS), Fig. X1.1, shall be prepared similar to that shown in Appendix X1 and shall be available for review during interpretation of the film.

8.2 *Radiographic Coverage* — Unless otherwise specified by a purchaser and supplier agreement, the extent of radiographic coverage shall be the maximum practical volume of the casting. Areas that require radiography shall be designated as illustrated in Fig. X1.2(a) and (b) of Appendix X1. When the shape or configuration of the casting is such that radiography is impractical, these areas shall be so designated on drawings or sketches that accompany the radiographs. Examples of casting geometries and configurations that may be considered impractical to radiograph are illustrated in Appendix X2.

8.3 *Radiographic Film Quality* — All radiographs shall be free of mechanical, chemical, handling-related, or other blemishes which could mask or be confused

with the image of any discontinuity in the area of interest on the radiograph. If any doubt exists as to the true nature of an indication exhibited by the film, the radiograph shall be retaken or rejected.

8.4 Radiographic Quality Level — The applicable job order or contract shall dictate the requirements for radiographic quality level. (See Practice E 1025 or Practice E 747 for guidance in selection of quality level.)

8.5 Acceptance Level — Radiographic acceptance levels and associated severity levels shall be stipulated by the applicable contract, job order, drawing, or other purchaser and supplier agreement.

8.6 Radiographic Density Limitations — Radiographic density in the area of interest shall be within 1.5 to 4.0 for either single or superimposed viewing.

8.7 Film Handling:

8.7.1 Darkroom Facilities — Darkroom facilities should be kept clean and as dust-free as practical. Safelights should be those recommended by film manufacturers for the radiographic materials used and should be positioned in accordance with the manufacturer's recommendations. All darkroom equipment and materials should be capable of producing radiographs that are suitable for interpretation.

8.7.2 Film Processing — Radiographic film processing shall be controlled in accordance with Guide E 999.

8.7.3 Film Viewing Facilities — Viewing facilities shall provide subdued background lighting of an intensity that will not cause troublesome reflections, shadows, or glare on the radiograph. The viewing light shall be of sufficient intensity to review densities up to 4.0 and be appropriately controlled so that the optimum intensity for single or superimposed viewing of radiographs may be selected.

8.7.4 Storage of Radiographs — When storage is required by the applicable job order or contract, the radiographs should be stored in an area with sufficient environmental control to preclude image deterioration or other damage. The radiograph storage duration and location after casting delivery shall be as agreed upon between purchaser and supplier. (See Guide E 1254 for storage information.)

9. Procedure

9.1 Time of Examination — Unless otherwise specified by the applicable job order or contract, radiography

may be performed prior to heat treatment and in the as-cast, rough-machined, or finished-machined condition.

9.1.1 Penetrameter (IQI) Selection — Unless otherwise specified in the applicable job order or contract, penetrameter (IQI) selection shall be based on the following: if the thickness to be radiographed exceeds the design thickness of the finished piece, the penetrameter (IQI) size shall be based on a thickness which does not exceed the design thickness of the finished piece by more than 20% or $\frac{1}{4}$ in. (6.35 mm), whichever is greater. In no case shall the penetrameter (IQI) size be based on a thickness greater than the thickness to be radiographed.

9.2 Surface Preparation — The casting surfaces shall be prepared as necessary to remove any conditions that could mask or be confused with internal casting discontinuities.

9.3 Source-to-Film Distance — Unless otherwise specified in the applicable job order or contract, geometric unsharpness (Ug) shall not be greater than one percent of the maximum part thickness being interpreted on the radiograph, or 0.070 in. (1.8 mm), whichever is less. Geometric unsharpness values shall be determined as specified in Guide E 94.

9.4 Direction of Radiation — The direction of radiation shall be governed by the geometry of the casting and the radiographic coverage and quality requirements stipulated by the applicable job order or contract. Whenever practicable, place the central beam of the radiation perpendicular to the surface of the film. Appendix X2 provides examples of preferred source and film orientations and examples of casting geometries and configurations on which radiography is impractical or very difficult.

9.5 Back-Scattered Radiation Protection:

9.5.1 Back-Scattered Radiation — (secondary radiation emanating from surfaces behind the film, that is, walls, floors, etc.) serves to reduce radiographic contrast and may produce undesirable effects on radiographic quality. A $\frac{1}{8}$ -in. (3.17 mm) lead sheet placed behind the film generally furnishes adequate protection against back-scattered radiation.

9.5.2 To detect back-scattered radiation, position a lead letter "B" [approximately $\frac{1}{8}$ in. (3.17 mm) thick by $\frac{1}{2}$ in. (12.7 mm) high] on the rear side of the film holder. If a light image (lower density) of the lead letter "B" appears on the radiograph, it indicates that more back-scatter protection is necessary. The appearance of a dark image of the lead letter "B" should be

disregarded unless the dark image could mask or be confused with rejectable casting defects.

9.6 Penetrameter (IQI) Placement — Place all penetrameters (IQI) being radiographed on the source side of the casting. Place penetrameters (IQIs) in the radiographic area of interest, unless the use of a shim or separate block is necessary, as specified in 9.7.6.

9.7 Number of Penetrameters (IQIs):

9.7.1 One penetrameter (IQI) shall represent an area within which radiographic densities do not vary more than +30% to -15% from the density measured through the body of the penetrameter (IQI).

9.7.2 When the film density varies more than -15% to +30%, two penetrameters (IQIs) used as follows will be acceptable: if one penetrameter (IQI) shows acceptable sensitivity representing the most dense portion of the exposure, and the second penetrameter (IQI) shows acceptable sensitivity representing the least dense portion of the exposure, then these two penetrameters (IQIs) shall qualify the exposure location within these densities, provided the density requirements stipulated in 8.6 are met.

9.7.3 For cylindrical or flat castings where more than one film holder is used for an exposure, at least one penetrameter (IQI) image shall appear on each radiograph. For cylindrical shapes, where a panoramic type source of radiation is placed in the center of the cylinder and a complete or partial circumference is radiographed using at least four overlapped film holders, at least three penetrameters (IQIs) shall be used. On partial circumference exposures, a penetrameter (IQI) shall be placed at each end of the length of the image to be evaluated on the radiograph with the intermediate penetrameters (IQIs) placed at equal divisions of the length covered. For full circumferential coverage, three penetrameters (IQIs) spaced 120° apart shall be used, even when using a single length of roll film.

9.7.4 When an array of individual castings in a circle is radiographed, the requirements of 9.7.1 or 9.7.2, or both, shall prevail for each casting.

9.7.5 If the required penetrameter (IQI) sensitivity does not show on any one film in a multiple film technique (see 9.11), but does show in composite (superimposed) film viewing, interpretation shall be permitted only by composite film viewing for the respective area.

9.7.6 When it is not practicable to place the penetrameter(s) (IQI) on the casting, a shim or separate

block conforming to the requirements of 6.7 may be used.

9.7.6.1 The penetrameter (IQI) shall be no closer to the film than the source side of that part of the casting being radiographed in the current view.

9.7.6.2 The radiographic density measured adjacent to the penetrameter (IQI) through the body of the shim or separate block shall not exceed the density measured in the area of interest by more than 15%. The density may be lighter than the area of interest density, provided acceptable quality level is obtained and the density requirements of 8.6 are met.

9.7.6.3 The shim or separate block shall be placed at the corner of the film holder or close to that part of the area of interest that is furthest from the central beam. This is the worst case position from a beam angle standpoint that a discontinuity would be in.

9.7.6.4 The shim or separate block dimensions shall exceed the penetrameter (IQI) dimensions such that the outline of at least three sides of the penetrameter (IQI) image shall be visible on the radiograph.

9.7.7 Film Side Penetrameter (IQI) — In the case where the penetrameter (IQI) cannot be physically placed on the source side and the use of a separate block technique is not practical, penetrameters (IQIs) placed on the film side may be used. The applicable job order or contract shall dictate the requirements for film side radiographic quality level (see 8.4).

9.8 Location Markers — The radiographic image of the location markers for the coordination of the casting with the film shall appear on the film, without interfering with the interpretation, in such an arrangement that it is evident that the required coverage was obtained. These marker positions shall be marked on the casting and the position of the markers shall be maintained on the part during the complete radiographic cycle. The RSS shall show all marker locations.

9.9 Radiographic Identification — A system of positive identification of the film shall be provided. As a minimum, the following shall appear on the radiograph: the name or symbol of the inspecting laboratory, the date, the casting identification number, and whether it is an original or subsequent exposure.

9.10 Subsequent Exposure Identification — All repair radiographs after the original (initial) shall have an inspection status designation that indicates the reason. Subsequent radiographs made by reason of a repaired area shall be identified with the letter "R" followed

by the respective repair cycle (that is, R-1 for the first repair, R-2 for the second repair, etc.). Subsequent radiographs that are necessary as a result of additional surface preparation should be identified by the letters “REG.”

9.11 Multiple Film Techniques — Two or more films of equal or different speeds in the same cassette are allowed, provided prescribed quality level and density requirements are met (see 9.7.2 and 9.7.5).

9.12 Radiographic Techniques:

9.12.1 Single Wall Technique — Except as provided in 9.12.2, radiography shall be performed using a technique in which the radiation passes through only one wall.

9.12.2 Double Wall Technique — For castings with an inside diameter of 4 in. or less, a technique may be used in which the radiation passes through both walls and both walls are viewed for acceptance on the same film. An adequate number of exposures shall be taken to ensure that required coverage has been obtained.

9.13 Safety — Radiographic procedures shall comply with applicable city, state, and federal regulations.

10. Radiograph Evaluation

10.1 Film Quality — Verify that the radiograph meets the quality requirements specified in 8.3, 8.4, 8.6, 9.5.2 and 9.7.

10.2 Film Evaluation — Determine the acceptance or rejection of the casting by comparing the radiographic image to the agreed upon acceptance criteria (see 8.5).

11. Reference Radiographs

11.1 Reference Radiographs E 155, E 186, E 192, E 272, E 280, E 310, E 446, E 505, E 689, and E 802 are graded radiographic illustrations of various casting discontinuities. These reference radiographs may be used to help establish acceptance criteria and may also be useful as radiographic interpretation training aids.

12. Report

12.1 The following radiographic records shall be maintained as agreed upon between purchaser and supplier:

12.1.1 Radiographic standard shooting sketch,

12.1.2 Weld repair documentation,

12.1.3 Film,

12.1.4 Film interpretation record containing as a minimum:

12.1.4.1 Disposition of each radiograph (acceptable or rejectable),

12.1.4.2 If rejectable, cause for rejection (shrink, gas, etc.),

12.1.4.3 Surface indication verified by visual examination (mold, marks, etc.), and

12.1.4.4 Signature of the film interpreter.

13. Precision and Bias

13.1 No statement has been made about either the precision or bias of this test method since the result merely states whether there is conformance to the criteria for success specified in the procedure.

14. Keywords

14.1 castings; gamma-ray; nondestructive testing; radiographic; radiography; x-ray

APPENDICES

(Nonmandatory Information)

X1. RADIOGRAPHIC STANDARD SHOOTING SKETCH (RSS)

X1.1 The radiographic standard shooting sketch (RSS) provides the radiographic operator and the radiographic interpreter with pertinent information regarding the examination of a casting. The RSS is designed to standardize radiographic methodologies associated with casting inspection; it may also provide a means of a purchaser and supplier agreement, prior to initiation of the inspection on a production basis. The use of a RSS is advantageous due to the many configurations associated with castings and the corresponding variations in tech-

niques for inspection of any particular one. The RSS provides a map of location marker placement, directions for source and film arrangement, and instructions for all other parameters associated with radiography of a casting. This information serves to provide the most efficient method for controlling the quality and consistency of the resultant radiographic representations.

X1.2 The RSS usually consists of an instruction sheet and sketch(es) of the casting; the instruction sheet specifies the radiographic equipment, materials, and technique-acceptance parameters for each location; the

GENERAL INFORMATION				CASTING IDENTIFICATION			
COMPANY PREPARING RSS				DRAWING NO.		REVISION	PIECE NO.
COMPANY PERFORMING RT				DESCRIPTION BODY			
FOUNDRY CASTING IDENTIFICATION METHOD				MATERIAL		MATERIAL SPEC.	
STAMPED ☒ ETCHED ☐ AT RT LOCATION 9-10				NI - CU			
SURFACE CONDITION WHEN RT'D				PATTERN NO.		HEAT NO.	
AS CAST ☐ ROUGH MACH'D ☐ FINISH MACH'D ☐							
RSS APPROVAL							
SUPPLIER				CUSTOMER			
1. DATE				1. DATE			
2. DATE				2. DATE			
RT PARAMETERS							
VIEWS	1-2 thru 4-1	5-6 thru 7-8	9-10	11-12	13		
SOURCE TYPE	IRID 192						
FINISHED THICKNESS	13/16"	3/4"	5/8"-2-1/8"	5/8"-2-3/8"	3/4"-2-3/8"		
THICKNESS WHEN RT'D	15/16"	7/8"	3/4"-2-5/16"	3/4"-2-1/2"	7/8"-2-1/2"		
PENETRATOR(S)	17	17	15 - 45	15 - 50	17 - 50		
SOURCE TO FILM DISTANCE	30"						
FILM TYPE	1		1 & 2				
FILM SIZE	5 X 7		8 X 10				
QUALITY LEVEL	2 - 2T						
ACCEPTANCE STANDARD	ASTM E-272						
SEVERITY LEVEL	2						
NOTES				REVISIONS			
				REV.	DESCRIPTION	APPROVAL	
				A	ORIGINAL ISSUE	SUPPLIER BY DATE	CUSTOMER BY DATE
RSS NO. XXX-YYY-22				REVISION A	PAGE 1	OF 3	

FIG. X1.1 Sample Radiographic Standard Shooting Sketch (RSS)

FIG. X1.1 SAMPLE RADIOGRAPHIC STANDARD SHOOTING SKETCH (RSS)

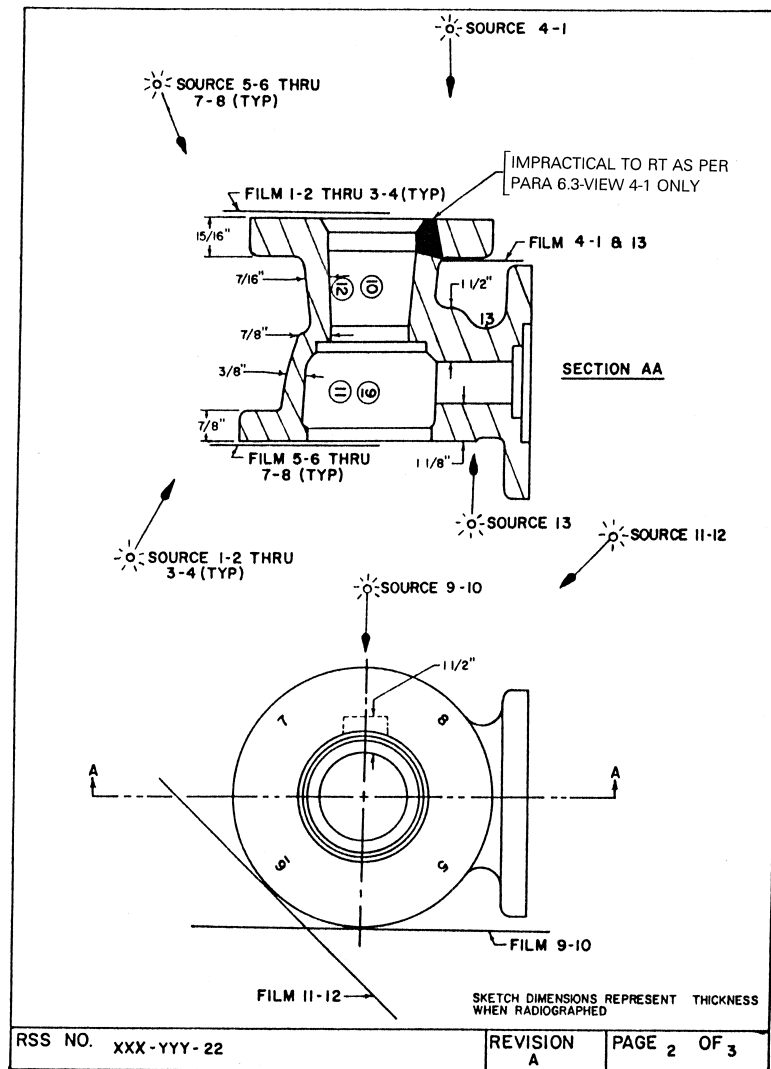


FIG. X1.2 SAMPLES OF RADIOGRAPHIC STANDARD SHOOTING SKETCHES (RSS)
(a) VIEWS ILLUSTRATING LAYOUT AND SOURCE AND FILM PLACEMENT

sketch(es) illustrate(s) the location, orientation, and the source and film arrangement for each location. Figures X1.1 and X1.2(a) and (b) of this appendix provide a typical instruction sheet and sketch sheets. As a minimum, the RSS should provide the following information. All spaces shall be filled in unless not applicable; in those cases, the space shall be marked NA.

X1.2.1 The instruction sheet should provide the following:

X1.2.1.1 Company preparing RSS and activity performing radiography.

X1.2.1.2 Casting identification including:

- (a) Drawing number,
- (b) Casting identification number,
- (c) Descriptive name (for example, pump casting, valve body, etc.),
- (d) Material type and material specification,
- (e) Heat number, and
- (f) Pattern number.

X1.2.1.3 Surface condition at time of radiography (as cast, rough machined, finished machined).

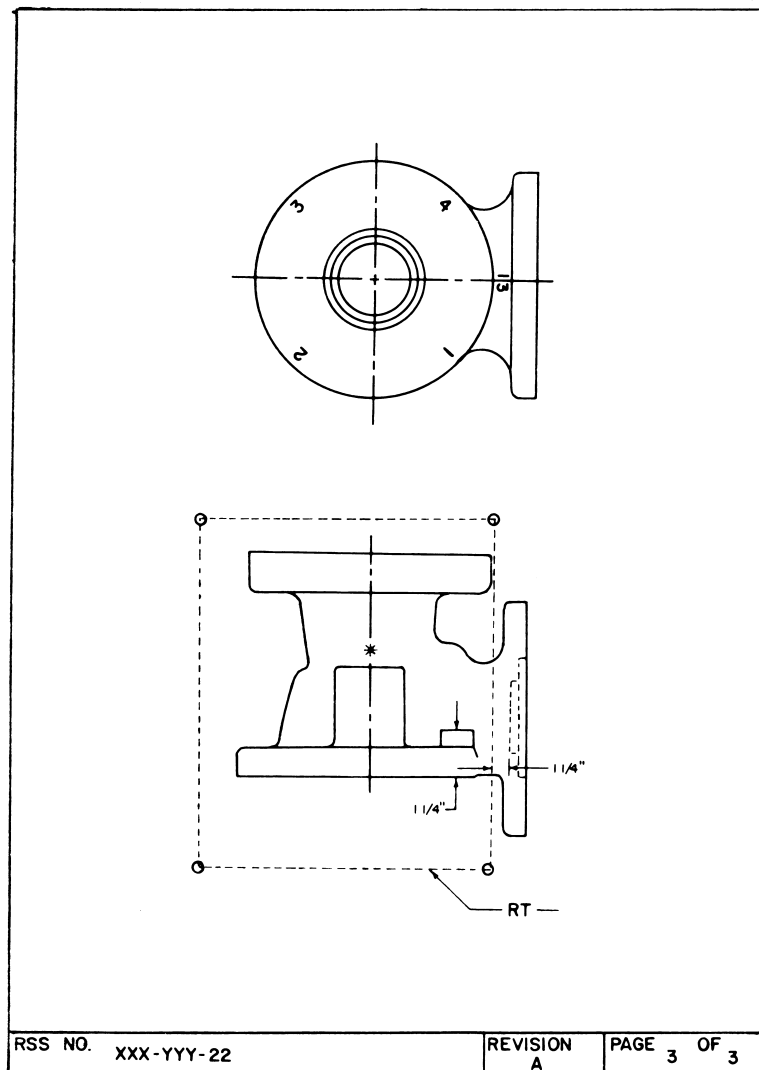


FIG. X1.2(b)
(b) VIEWS ILLUSTRATING LAYOUT AND EXTENT OF COVERAGE

X1.2.1.4 Spaces for approval (as applicable).

X1.2.1.5 *Radiographic Technique Parameters for Each Location:*

- (a) Radiographic location designation,
- (b) Source type and size,
- (c) Finished thickness,
- (d) Thickness when radiographed,
- (e) Penetrators,
- (f) Source to film distance,
- (g) Film type and quantity,
- (h) Film size,

- (i) Required penetrometer (IQI) quality level,
- (j) Radiographic acceptance standard, and
- (k) Applicable radiographic severity level.

X1.2.2 The sketch(es) should provide the following:

X1.2.2.1 Location marker placement.

X1.2.2.2 Location of foundry's identification pad or symbol on the casting.

X1.2.2.3 Designation of areas that require radiography (as applicable).

X1.2.2.4 Designation of areas that are considered impractical or very difficult to radiograph (see 1.2 and 8.2).

X1.2.2.5 Radiographic source and film arrangement and radiation beam direction for each location.

NOTE X1.1 — The RSS should designate the involved locations and stipulate that the technique for those locations is typical, for sections of the casting on which a continuing series of locations are to be radiographed with the same basic source and film arrangement for each location.

X1.2.3 Figure X1.1 of this appendix provides a sample RSS that has been developed for a typical production application, and Fig. X1.2(a) and (b) provide sample RSS sketches that have been developed for a typical production application.

X1.2.4 The RSS may not provide what is considered to be the most effective means of technique control for all radiographic activities, but, in any event, some means of technique standardization should be employed. As a general rule, it is a beneficial practice for the supplier to solicit purchaser approval of the radiographic methodology prior to performing production radiography. This generally entails the demonstration of the adequacy of the methodology by submitting the proposed technique parameters and a corresponding set of

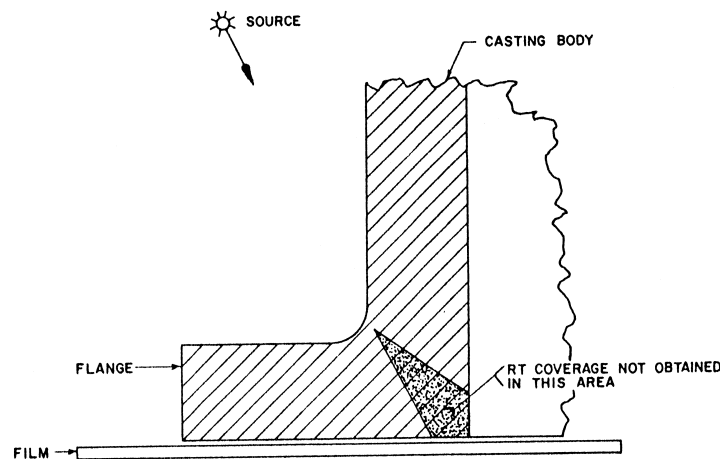
pilot radiographs to the purchaser for review. Purchaser approval of the technique shall be addressed in the applicable job order or contract.

X2. PREFERRED SOURCE AND FILM ALIGNMENT FOR FLANGE RADIOGRAPHY AND EXAMPLES OF AREAS THAT ARE CONSIDERED IMPRACTICAL TO RADIOGRAPH

X2.1 Preferred Source and Film Alignment for Flange Radiography — The effective use of radiography for assessing material soundness in casting areas where a flange joins a body is somewhat limited by the source and film alignment that the geometric configuration of these areas requires. The following figures describe source and film alignments that can be employed and discusses the limits and benefits of each.

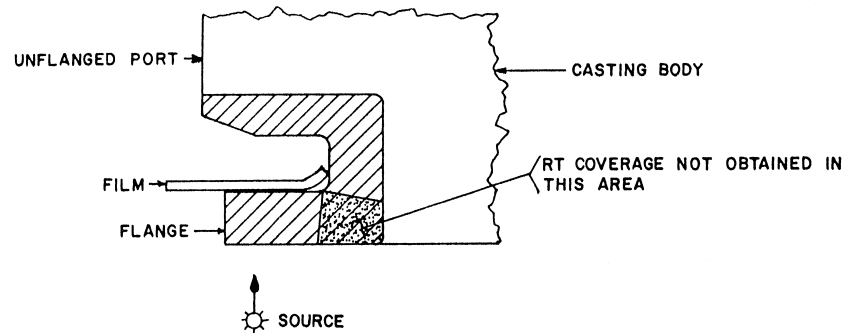
X3. EXAMPLES OF AREAS THAT ARE CONSIDERED TO BE IMPRACTICAL TO RADIOGRAPH

X3.1 Certain casting geometry configuration are inaccessible for conventional source and film arrangements that will provide meaningful radiographic results. These areas generally involve the juncture of two casting sections. The following illustrations provide typical examples of such areas.



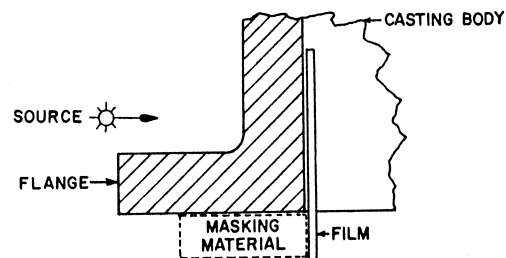
NOTE—For general application, this alignment provides the most effective compromise of quality radiography and maximum obtainable coverage.

FIG. X2.1 PREFERRED SOURCE AND FILM ALIGNMENT



NOTE—This alignment provides a suitable alternative when other casting appendages (bosses, flanges, etc.) project into the radiation path as illustrated in Fig. X2.2 when this alignment is used, additional losses in coverage (as opposed to Fig. X2.1) should be expected and noted accordingly on the applicable RSS.

FIG. X2.2 PERMISSIBLE SOURCE AND FILM ALIGNMENT WHEN FIG. X2.1 CANNOT BE APPLIED DUE TO CASTING GEOMETRY



NOTE—This alignment is permissible if the radiation source energy and film multi-load capabilities are sufficient to afford compliance with the technique requirements stipulated herein. This alignment will generally require the use of filters or masking to reduce the influence of radiation that undercuts the thicker areas and reduces overall radiographic quality.

FIG. X2.3 ALLOWABLE SOURCE FILM ALIGNMENT AS GOVERNED BY SOURCE ENERGY AND MULTI-FILM LOAD ACCEPTANCE DENSITY LATITUDE

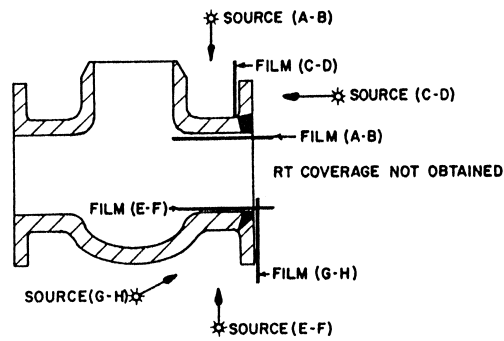


FIG. X3.1 AREAS INVOLVING FLANGES

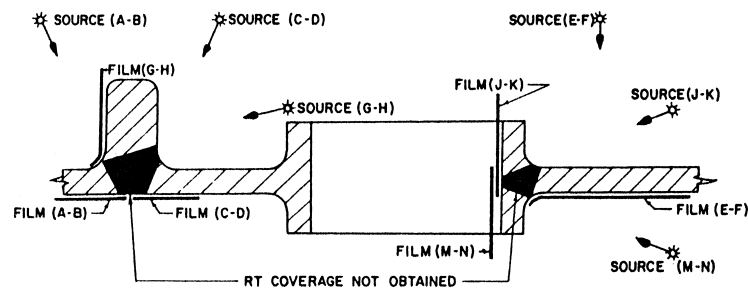


FIG. X3.2 AREAS INVOLVING OTHER JUNCTURES

STANDARD PRACTICE FOR CALIBRATION OF TRANSMISSION DENSITOMETERS



SE-1079



(Identical with ASTM Specification E 1079-97)

1. Scope

1.1 This practice covers the calibration of transmission densitometers used to perform radiographic film density measurements (see Note).

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE — For further information on the design and use of densitometers, the following literature is suggested as additional background information: Guide E 94 and ANSI documents PH2.19 and PH2.36.

2. Referenced Documents

2.1 ASTM Standards:

E 94 Guide for Radiographic Testing

E 1316 Terminology for Nondestructive Examinations

2.2 ANSI Documents:

ANSI/NAPM IT2.19-1994, Photography — Density Measurements — Part 2: Geometric Conditions for Transmission Density

ANSI/NAPM IT2.16-1996, Photography — Density Measurements — Part 1: Terms, Symbols, and Notations

3. Terminology

3.1 Definitions — For definitions of terms used in this practice, see Terminology E 1316.

4. Significance and Use

4.1 This practice provides a means for calibrating transmission densitometers used for the measurement of radiographic film density. A transmission densitometer calibrated in accordance with this practice provides the assurance that accurate density values of radiographs are obtained.

5. Apparatus

5.1 Apparatus should consist of the following:

5.1.1 A calibrated step tablet shall be used. The step tablet may be a NIST X-ray Step Tablet (Standard Reference Material SRM 1001) or alternately a step tablet from another supplier, which is traceable to the NIST SRM 1001 X-ray Step Tablet. The step tablet shall have at least five step densities ranging from 0.3 through 3.9. The step tablet may have additional step densities less than 0.3 and greater than 3.9. A calibration certificate shall be provided with the step tablet indicating the tablet ID and recorded values for each step density. For suppliers of step tablets other than NIST, the certificate shall indicate conformance of traceability to NIST instrumentation used in the calibration process, applicable ANSI standards used, verification of measurement on a NIST SRM 1001 step tablet, the ID number of the SRM 1001 step tablet, and calibration date of the step tablet. Precautions should be taken in the storage, handling, and use of the step tablet. In the event it becomes scratched, blemished, or exhibits other signs of deleterious wear, it should be replaced immediately. The step tablet shall be replaced four years from date of first use.

5.1.2 *Transmission Densitometers*, with either direct-scale readout or digital readout displays specifi-

cally manufactured for the purpose of measuring the range of film densities described in 5.1.1 may be used.

5.1.3 *Manufacturer's Operating Instructions for Appropriate Transmission Densitometer.*

6. Calibration

6.1 Full-scale linearity calibration should be performed at least every 90 days during use as follows:

6.1.1 Allow a minimum of 30-min "warm-up" time (or the manufacturer's recommended warm-up time) to stabilize circuitry before starting the calibration procedure or the periodic verification checks described in Section 8. Adjust the "0" reading of the densitometer after the warm-up period.

6.1.2 Select and position for reading the neutral density closest to 0.3, 3.0, and 3.9 on the calibrated step tablet. Read and record the density for each step.

6.1.3 Compare the densities recorded with the actual density values on the calibrated step tablet or the density values listed on the calibration certificate. If the densitometer has been calibrated properly, the densities at 0.3, 3.0, and 3.9 steps should not vary more than ± 0.05 density units. If any of the recorded density values vary more than ± 0.05 density units from the density values on the calibrated step tablet, the linearity of the densitometer is out of tolerance and should be corrected.

7. Records and Associated Documentation

7.1 Note and record the calibrated readings, required by 6.1.2 in an appropriate calibration log. A pressure-sensitive label or tag that indicates the date the calibra-

tion was performed, and the identification of the individual performing the calibration, may be applied to the densitometer to verify the calibration reference check recorded in the calibration log.

7.2 An alternative calibration documentation system may be used provided the calibration traceability requirements identified in 7.1 can be satisfied and documented properly.

8. Periodic Verification

8.1 Periodic calibration verification checks using the procedure described in Section 6 should be performed at the beginning of each shift, after 8 h of continuous operation, or change of apertures, whichever occurs first.

8.1.1 If the verification reading is within ± 0.05 of the density values recorded in the calibration log required by 7.1, the densitometer is ready for continued use. It is not necessary to record density values when they are within the acceptable tolerance. If the density values are not within the tolerance, recalibration is required and it shall be performed in accordance with Section 6.

8.1.2 If the calibration verification check shows a variation greater than ± 0.05 , then all radiographs examined since the last acceptable daily density check should be subject to a reverification for density after the densitometer has been recalibrated.

8.2 Consult the Manufacturer's Technical Manual for troubleshooting information.

9. Keywords

9.1 calibration; densitometer; density; periodic verification; radiographic film

STANDARD TEST METHOD FOR DETERMINING THE FOCAL SIZE OF IRIIDIUM-192 INDUSTRIAL RADIOGRAPHIC SOURCES



SE-1114



[Identical with ASTM Specification E 1114-92 (R1997)]

1. Scope

1.1 This test method covers the determination of the focal size of an iridium-192 radiographic source. The determination is based upon measurement of the image of the iridium metal source in a projection radiograph of the source assembly and comparison to the measurement of the image of a reference sample in the same radiograph.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

E 999 Guide for Controlling the Quality of Industrial Radiographic Film Processing
E 1316 Terminology for Nondestructive Testing

3. Terminology

3.1 For definitions of terms relating to this test method, refer to Terminology E 1316.

4. Significance and Use

4.1 One of the factors affecting the quality of a radiographic image is geometric unsharpness. The degree of geometric unsharpness is dependent upon the

focal size of the source, the distance between the source and the object to be radiographed, and the distance between the object to be radiographed and the film. This test method allows the user to determine the focal size of the source and to use this result to establish source to object and object to film distances appropriate for maintaining the desired degree of geometric unsharpness.

5. Apparatus

5.1 Subject Iridium-192 Source, the focal size of which is to be determined. The appropriate apparatus and equipment for the safe storage, handling, and manipulation of the subject source, such as a radiographic exposure device (also referred to as a gamma ray projector or camera), remote control, source guide tube, and source stop are also required.

5.2 Reference Sample (see Figs. 1,2, and 3) — The reference sample shall be of material which is not radioactive. The recommended material is iridium. However, substitutes such as platinum, tungsten, or other material of similar radiopacity may be used. The sample should be of the same geometric shape as the subject source, should be approximately the same size as the subject source, and should be positioned on or within a shim or envelope to simulate the source capsule wall. The resulting radiographic contrast, with reference to adjacent background density of the image of the reference sample, should be approximately the same as that of the subject source. The actual dimensions of the reference sample should be determined to the nearest 0.025 mm (0.001 in.).

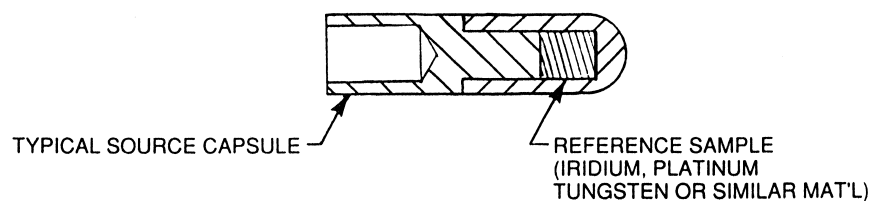


FIG. 1 REFERENCE SAMPLE IN STANDARD SOURCE ENCAPSULATION

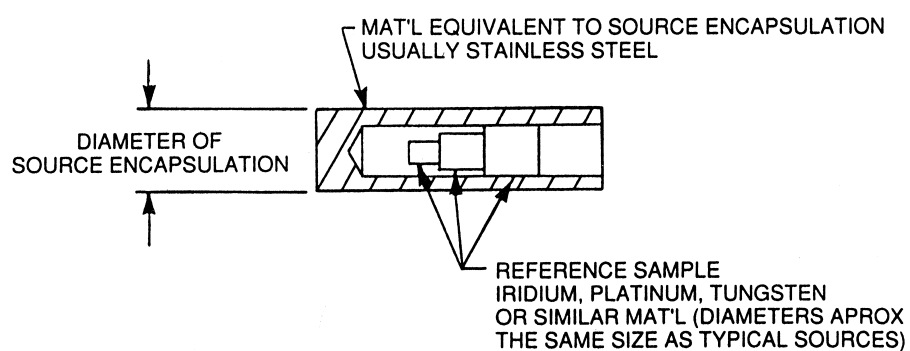


FIG. 2 ALTERNATE REFERENCE SAMPLE ARRANGEMENT

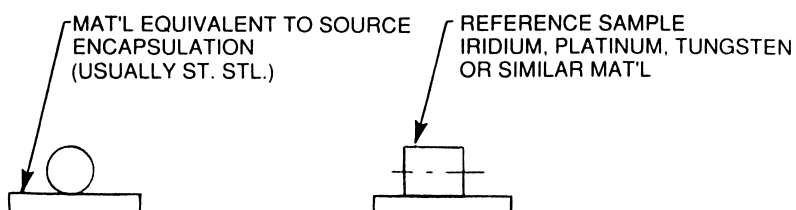


FIG. 3 ALTERNATE REFERENCE SAMPLE ARRANGEMENT

TABLE 1
EXAMPLES OF TYPICAL X-RAY GENERATOR
OUTPUT REQUIREMENTS FOR RELATED IRIIDIUM¹⁹²
SOURCE ACTIVITIES

Subject Iridium ¹⁹² Source Radiation		Typical X-ray Generator Output Requirements		
Activity (Curie)	Output (Rh at 1 m)	Potential	Current	
30	14.4	160 kV	5 mA	
		or 200 kV	3 mA	
100	48.0	160 kV	10 mA	
		or 250 kV	4 mA	
200	96.0	160 kV	20 mA	
		or 250 kV	8 mA	
		or 300 kV	6 mA	

5.3 X-ray Generator, capable of producing a radiation intensity (roentgen per hour at one metre) at least ten times greater than that produced by the subject source. Examples of typical X-ray generator output requirements that satisfy this criterion are presented in Table 1.

5.4 Film, industrial type fine grain, extra fine grain, or ultra fine grain as defined by the film manufacturer shall be used. Selection of film type should be determined by such factors as the required radiographic quality level, equipment capability, materials, and so forth. The films selected must be capable of demonstrating the required image quality. No intensifying screens should be used. The film should be processed in accordance with Guide E 999.

5.5 Image Measurement Apparatus — This apparatus is used to measure the size of the image of the focal spot. The apparatus shall be an optical comparator with built-in graticule with 0.1 mm divisions or 0.001 in. divisions and magnification of 5× to 10×.

6. Procedure

6.1 Set up the exposure arrangement as shown in Figs. 4, 5, 6, and 7. Position the X-ray tube directly over the center of the film. The film plane must be normal to the central ray of the X-ray beam. The X-ray focal spot should be 0.90 m (36 in.) from the film. Position the reference sample and apparatus used to locate the subject source (source stop) as close together as possible and directly over the center of the film. The plane of the source stop and reference sample must be parallel to the film and normal to the central

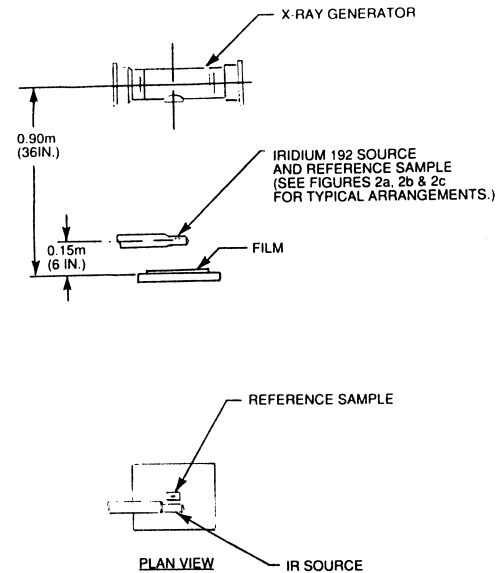


FIG. 4 TYPICAL EXPOSURE ARRANGEMENT

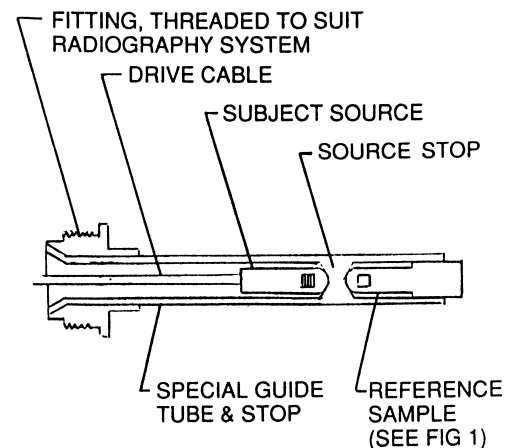


FIG. 5 TYPICAL ARRANGEMENT USING A SPECIALLY DESIGNED GUIDE TUBE

ray of the X-ray beam. The source stop and reference sample should be 0.15 m (6 in.) from the film. The source stop should be connected to the radiographic exposure device by the shortest source guide tube practicable in order to minimize fogging of the film during source transit.

6.2 Place identification markers to be imaged on the film to identify, as a minimum, the identification (serial number) of the subject source, the size of the reference

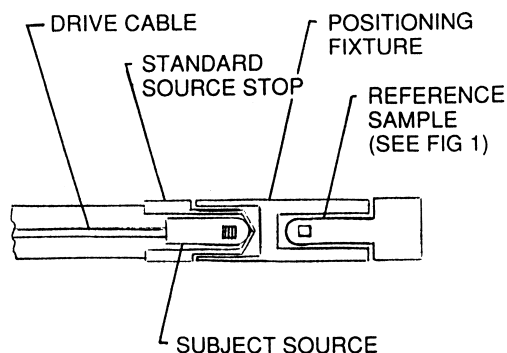


FIG. 6 TYPICAL ARRANGEMENT USING A STANDARD GUIDE TUBE AND SPECIAL POSITIONING FIXTURE

sample, the identification of the organization performing the determination, and the date of the determination. Care should be taken to ensure that the images of the subject source and reference sample will not be superimposed on the image of the identification markers.

6.3 Exposure — Select the X-ray tube potential (kV), X-ray tube current (mA), and exposure time such that the density in the image of the envelope surrounding the reference sample does not exceed 3.0 and that the density difference between the image of the reference sample and the image of the envelope surrounding the reference sample is at least 0.10.

NOTE — The actual parameters that will produce acceptable results may vary between X-ray units, and trial exposures may be necessary.

6.3.1 Energize the X-ray generator and, at the same time, manipulate the subject source into the exposure position in the source stop. It is important that this be performed as quickly as possible to minimize fogging of the film.

6.3.2 At the conclusion of the exposure time, deenergize the X-ray generator and, at the same time, return the subject source to the proper shielded storage position.

6.3.3 Process the film.

7. Measurement of Focal Dimensions

7.1 View the radiograph with sufficient light intensity for adequate viewing. Using an optical comparator with built-in graticule as described in 5.5, measure the linear dimensions of the image of the focal spot of the subject

source and the reference sample. Take measurements from the perceptible edges of the image. When performing the physical measurements with the optical comparator, the actual measured values shall be to the nearest graduation on the graticule scale being used.

7.2 The focal size for a given technique is the maximum projected dimension of the source in the plane perpendicular to a line drawn from the source to the object being radiographed. Therefore, sufficient measurements of the image of the iridium must be made to determine the focal size of the source in any orientation. Sections 7.2.1 through 7.2.4 serve as examples.

7.2.1 Uniform Right Circular Cylinder (see Fig. 8) — Determine the focal size of a uniform right circular cylindrical source by measuring the diameter, d , the height, h , and the diagonal, m , as illustrated in Fig. 8 and computing the actual dimensions as described in 8.1.

7.2.2 Sphere (see Fig. 9) — Determine the focal size of a spherical source by measuring the diameter, d , as illustrated in Fig. 9 and computing the actual dimension as described in 8.1.

7.2.3 Nonuniform Stack of Right Circular Cylinders (see Fig. 10) — Determine the focal size of a nonuniform stack of right circular cylindrical components of a source by measuring the intrinsic diameter, d , the height, h , and the effective maximum dimension, m , as illustrated in Fig. 10 and computing the actual dimensions as described in 8.1.

7.2.4 Separated Stack of Right Circular Cylinders (see Fig. 11) — Determine the focal size of a separated stack of right circular cylindrical components of a source by measuring the intrinsic diameter, d , the effective height, h , and the effective maximum dimension, m , as illustrated in Fig. 11 and computing the actual dimensions as described in 8.1.

8. Calculation and Evaluation

8.1 Measure the linear dimension of interest in the subject source image and measure the same linear dimension in the reference sample image (that is, the diameter of each). The actual dimension of the subject source is computed from the following:

$$a = \frac{bc}{d}$$

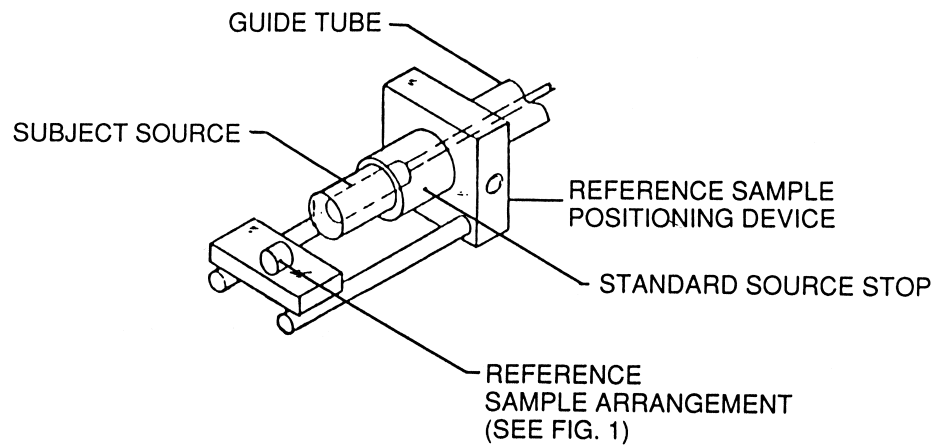


FIG. 7 TYPICAL ARRANGEMENT USING REFERENCE SAMPLE POSITIONING DEVICE

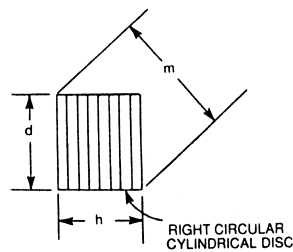


FIG. 8 UNIFORM RIGHT CIRCULAR CYLINDER

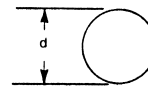


FIG. 9 SPHERE

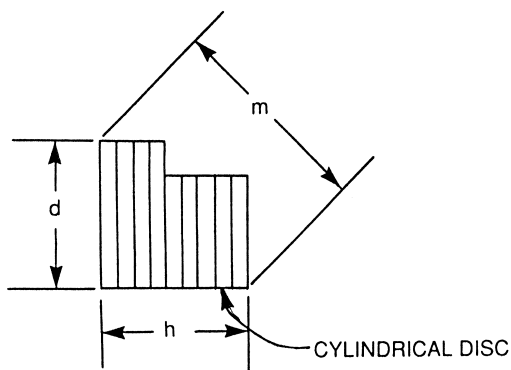


FIG. 10 NONUNIFORM CYLINDRICAL STACK

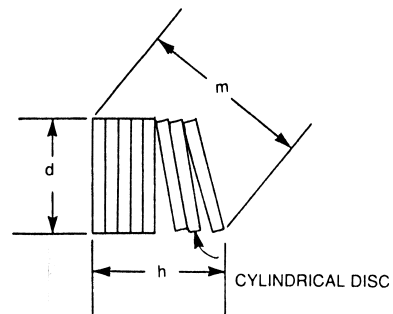


FIG. 11 SEPARATED CYLINDRICAL STACK

where:

a = actual dimension of the subject source,
 b = actual dimension of the reference sample,
 c = measured dimension of the subject source image, and
 d = measured dimension of the reference sample image.

number of the source, the name of the organization making the determination, the date the determination was made, a description of the shape of the source (or an appropriate sketch), and the calculated actual dimensions. The actual radiograph should accompany the report.

9. Report

9.1 A report of the focal size of an iridium-192 source should indicate the model number and serial

10. Keywords

10.1 cylinder(s); focal size; iridium 192; radiographic source; reference sample; sphere

STANDARD TEST METHOD FOR MEASUREMENT OF FOCAL SPOTS OF INDUSTRIAL X-RAY TUBES BY PINHOLE IMAGING



SE-1165



[Identical with ASTM Specification E 1165-92 (R1996)]

1. Scope

1.1 This test method provides instructions for determining the length and width dimensions of line focal spots in industrial X-ray tubes (see Note 1). This determination is based on the measurement of an image of a focal spot that has been radiographically recorded with a “pinhole” projection/imaging technique.

NOTE 1 — Line focal spots are associated with vacuum X-ray tubes whose maximum voltage rating does not generally exceed 500 kV.

1.2 This test method may not yield meaningful results on focal spots whose nominal size is less than 0.3 mm (0.011 in.). (See Note 2.)

NOTE 2 — The X-ray tube manufacturer may be contacted for nominal focal spot dimensions.

1.3 This test method may also be used to determine the presence or extent of focal spot damage or deterioration that may have occurred due to tube age, tube overloading, and the like. This would entail the production of a focal spot radiograph (with the pinhole method) and an evaluation of the resultant image for pitting, cracking, and the like.

1.4 Values stated in SI units are to be regarded as the standard. Inch-pound units are provided for information only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Document

2.1 ASTM Standard:
E 999 Guide for Controlling the Quality of Industrial Radiographic Film Processing

3. Terminology

3.1 Definitions of Terms Specific to This Standard

3.1.1 actual focal spot — the X-ray producing area of the target as viewed from a position perpendicular to the target surface (see Fig. 1).

3.1.2 effective focal spot — the X-ray producing area of the target as viewed from a position perpendicular to the tube axis in the center of the X-ray beam (see Fig. 1).

3.1.3 line focal spot — a focal spot whose projected pinhole image consists primarily of two curved lines (see Fig. 2).

4. Significance and Use

4.1 One of the factors affecting the quality of a radiographic image is geometric unsharpness. The degree of geometric unsharpness is dependent upon the focal size of the radiation source, the distance between the source and the object to be radiographed, and the distance between the object to be radiographed and the film. This test method allows the user to determine the focal size of the X-ray source and to use this result to establish source to object and object to film distances appropriate for maintaining the desired degree of geometric unsharpness.

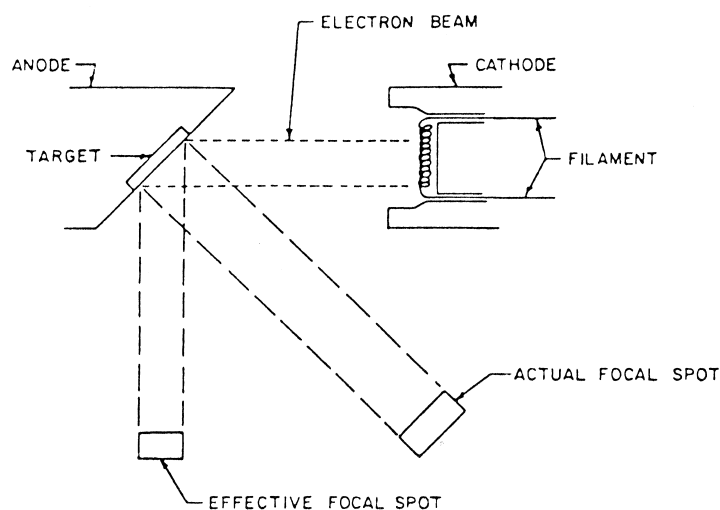
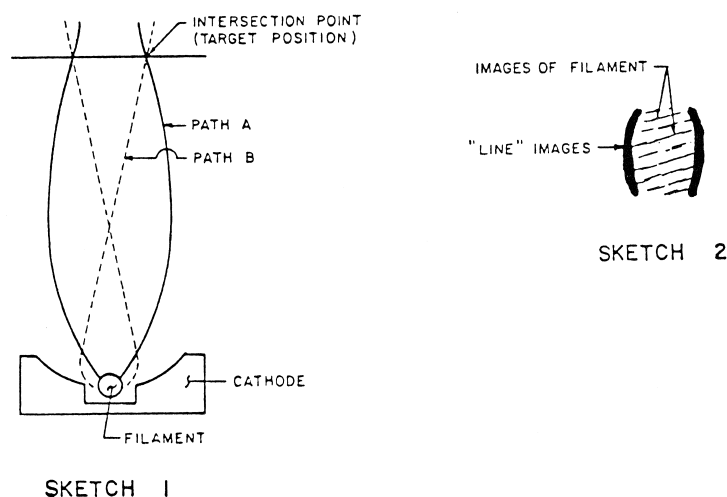


FIG. 1 ACTUAL/EFFECTIVE FOCAL SPOT



NOTE—During the production of X-rays the electrons are accelerated from the filament to the target in two separate paths (see Sketch 1). Electrons emitted at the front of the filament travel primarily along Path A, and electrons emitted at the backside of the filament travel primarily along Path B. Note that these two paths intersect at a certain point; this is the point at which the target is positioned. As a result, the pinhole picture of the focal spot shows two lines that correspond with the intersections of Paths A and B at the target (see Sketch 2).

FIG. 2 LINE FOCAL SPOT

TABLE 1
PINHOLE DIAPHRAGM DESIGN REQUIREMENTS (DIMENSION)^A

NOTE — The pinhole diaphragm shall be made from one of the following materials:

- (1) An alloy of 90% gold and 10% platinum,
- (2) Tungsten,
- (3) Tungsten carbide,
- (4) Tungsten alloy,
- (5) Platinum and 10% Iridium alloy, or
- (6) Tantalum.

Nominal Dimension of Focal Spot, mm (in.) ^B	Nominal Diameter of Diaphragm Opening, mm (in.)	Required "D" and "L" Dimensions, mm (in.)	
		D	L
>0.3 to 1.2 (0.011 to 0.046) incl	0.030 (0.0011)	0.030 ± 0.005 (0.0011 ± 0.0002)	0.075 ± 0.010 (0.0029 ± 0.0004)
>1.2 to 2.5 (0.046 to 0.097) incl	0.075 (0.0029)	0.075 ± 0.005 (0.0029 ± 0.0002)	0.350 ± 0.010 (0.014 ± 0.0004)
>2.5 (0.097)	0.100 (0.0039)	0.100 ± 0.005 (0.0039 ± 0.0002)	0.500 ± 0.010 (0.02 ± 0.0004)

^A See Fig. 3.

^B Nominal focal spot dimensions may be obtained from the X-ray tube manufacturer.

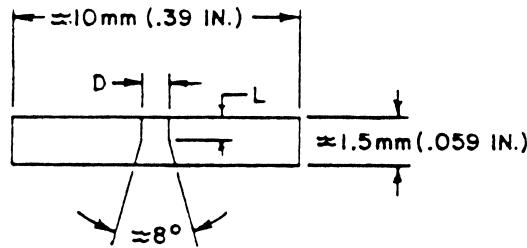


FIG. 3 PINHOLE DIAPHRAGM DESIGN

5. Apparatus

5.1 Pinhole Diaphragm — The pinhole diaphragm shall conform to the design and material requirements of Table 1 and Fig. 3.

5.2 Camera — The pinhole camera assembly consists of the pinhole diaphragm, the shielding material to which it is affixed, and any mechanism that is used to hold the shield/diaphragm in position (jigs, fixtures, brackets, and the like; see Fig. 4).

5.3 Film — Industrial type extra fine grain. No intensifying screens are to be used. The film shall be processed in accordance with Guide E 999.

5.4 Image Measurement Apparatus — This apparatus is used to measure the size of the image of the focal spot. The apparatus shall be an optical comparator with

built-in graticule with 0.1 mm or 0.001 in., or both divisions and magnification of 5× to 10× (or equivalent).

6. Procedure

6.1 If possible, use a standard 91.44 cm (36 in.) focal spot to film plane distance (FFD) for all exposures. If machine geometry or accessibility limitations will not permit the use of a 91.44 cm (36 in.) FFD, use the maximum attainable FFD (in these instances adjust the relative distances between focal spot, pinhole, and film accordingly to suit the image enlargement factors specified in Table 2). The distance between the focal spot and the pinhole is based on the nominal size of the focal spot being measured and the desired degree of image enlargement (see Fig. 5). The specified focal spot to pinhole distance (FHD) for the different nominal focal spot size ranges is provided in Table 2. Position the pinhole such that it is within ±1° of the central axis of the X-ray beam. Fig. 6 illustrates a typical focal spot exposure arrangement.

NOTE 3 — The accuracy of the pinhole system is highly dependent upon the relative distances between (and alignment of) the focal spot, the pinhole, and the film. Accordingly, specially designed apparatus may be necessary in order to assure compliance with the above requirements. Figure 7 provides an example of a special collimator that can be used to ensure conformance with the ±1° alignment tolerance. Some other standards impose very stringent alignment requirements and express these requirements in terms of radial tolerances. These documents do not, however, address any means for assuring compliance with such tolerances. In order to simplify the focal spot radiography technique and to improve the

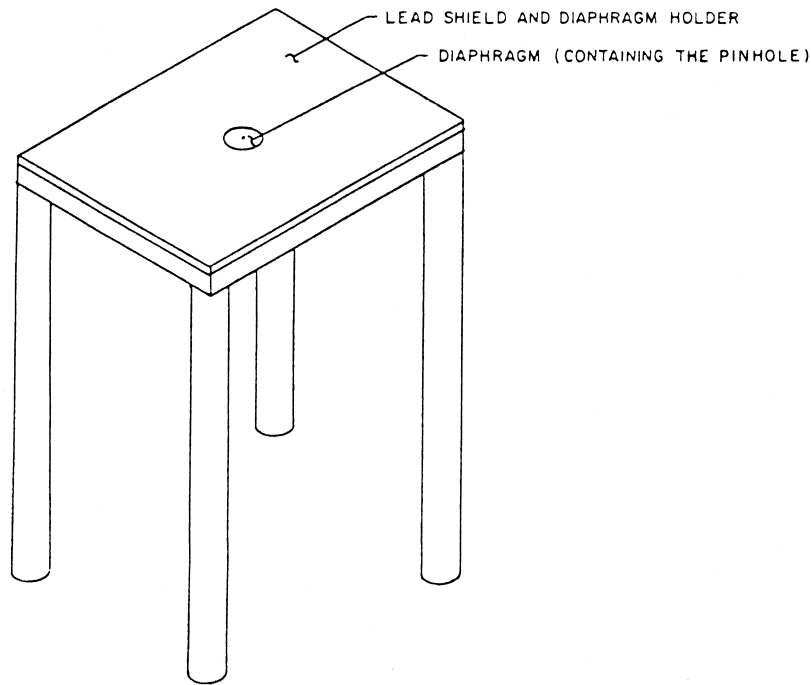


FIG. 4 PINHOLE CAMERA (TYPICAL)

TABLE 2
IMAGE ENLARGEMENT FACTORS

Nominal Focal Spot Size, mm (in.)	Enlargement Factor	Distance Between Focal Spot and Pinhole (FHD), cm (in.) ⁴
0.3 to 1.2 (0.011 to 0.046) incl	3×	22.9 (9)
>1.2 to 2.5 (0.046 to 0.097) incl	2×	30.5 (12)
>2.5 (0.097)	1×	45.7 (18)

⁴ When using a technique that entails the use of enlargement factors and a 91.44 cm (36 in.) focal spot to film distance (FFD) is not possible (see 6.1), the distance between the focal spot and the pinhole (FHD) shall be adjusted to suit the actual focal spot to film distance (FFD) used [for example, if a 61 cm (24 in.) FFD is used, the FHD shall be 15.25 cm (6 in.) for 3× enlargement, 20.32 cm (8 in.) for 2× enlargement, and the like].

overall practicality of the procedure, it is considered that a workable alignment tolerance, and a means of assuring conformance with that tolerance, is appropriate. Accordingly, this standard addresses tolerances in angular terms and provides a method for assuring compliance with these tolerances. This provides a practical means of meeting the precision and bias requirements of Section 9.

6.2 Position the film as illustrated in Fig. 6. The exposure identification appearing on the film (by radio-

graphic imaging) should be X-ray machine identity (that is, make and serial number), organization making the radiograph, and date of exposure.

6.3 Adjust the kilovoltage and milliamperage settings on the X-ray machine to that specified in Table 3.

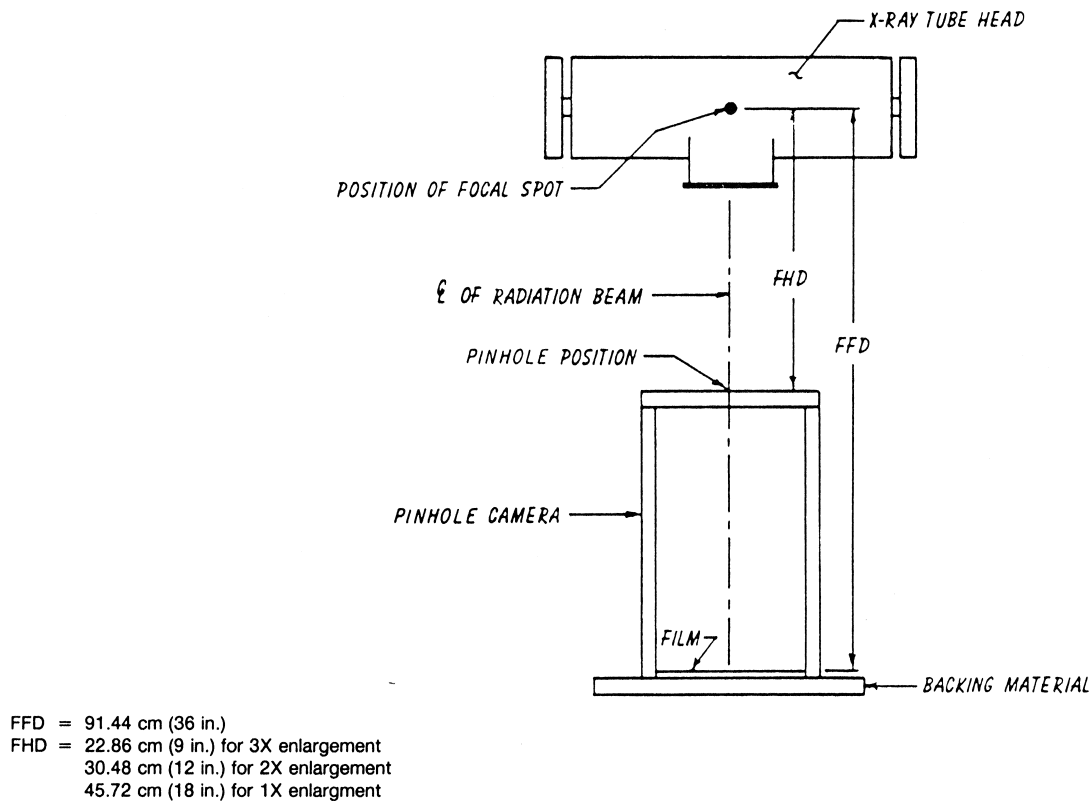
6.4 Expose the film such that the density of the darkest portion of the focal spot image conforms to the limits specified in Table 4. Density measurement shall be as illustrated in Fig. 8. Density shall be controlled by exposure time only.

6.5 Process the film in accordance with Guide E 999.

6.6 Focal Spot Measurement:

6.6.1 Back Lighting — Back lighting shall be such that the focal spot image can be easily and comfortably viewed.

6.6.2 Place the magnification graticule (handheld optical comparator) in intimate contact with the film for the measurement determination. Determine an imaginary “box” that represents the perceptible edges of the focal spot image [see Fig. 9(a)] for the extremities measurement.



NOTE—See 6.1 and Table 1 if a 91.44 cm (36 in.) FFD is not achievable.

FIG. 5 SCHEMATIC OF FHD/FFD RELATIONSHIP

6.6.3 Measure the focal spot image in two directions [see Fig. 9(b)]:

6.6.3.1 Direction A — Parallel to the axis of the tube.

6.6.3.2 Direction B — Perpendicular to the axis of the tube.

7. Calculation of Results

7.1 Multiply the measured “A” direction dimension by a correction factor of 0.7 to determine the actual “A” dimension (see Note 4). The measured “B” direction dimension is representative of actual size.

NOTE 4 — The need for the 0.7 fractional multiplier for correction of the measured image length arises from the fact that the lengthwise distribution of energy in the focal spots of line-focus tubes tends to be peaked in the center and diminishes gradually to zero at the ends. Hence, the effective length, (that is, resultant effect on radiographic definition and film density distribution) cannot be stated as equal to the measured length.

7.2 If an image enlargement technique was used, divide the “A” and “B” direction measurements by the pertinent enlargement factor to obtain actual focal spot size (see Fig. 5 and Table 2).

8. Report

8.1 A report documenting the focal spot size determination should include the machine model number and serial number, the X-ray tube serial number, the focal spot(s) that was measured (some machines have dual focal spots), the set-up and exposure parameters (for example, kilovoltage, milliamps, enlargement factor, and the like) date, name of organization, and estimated beam time hours (if available).

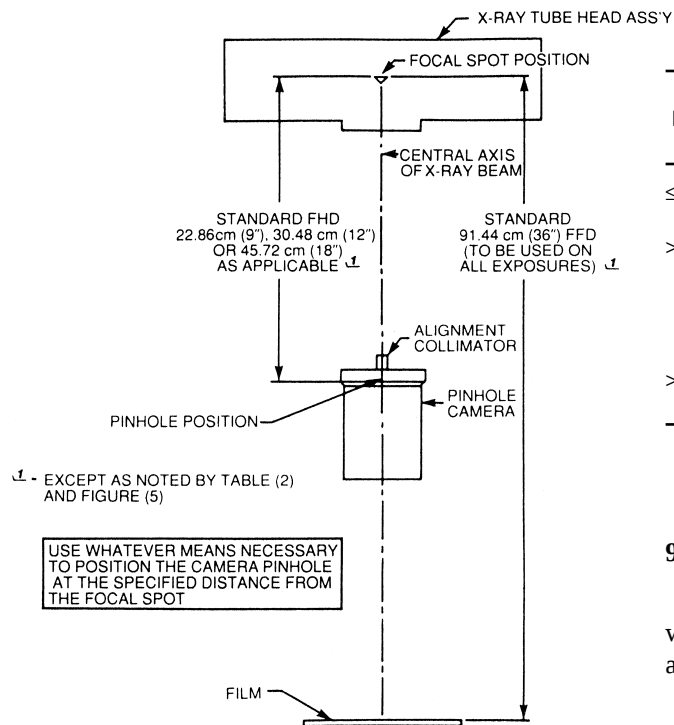


FIG. 6 EXPOSURE SET-UP SCHEMATIC

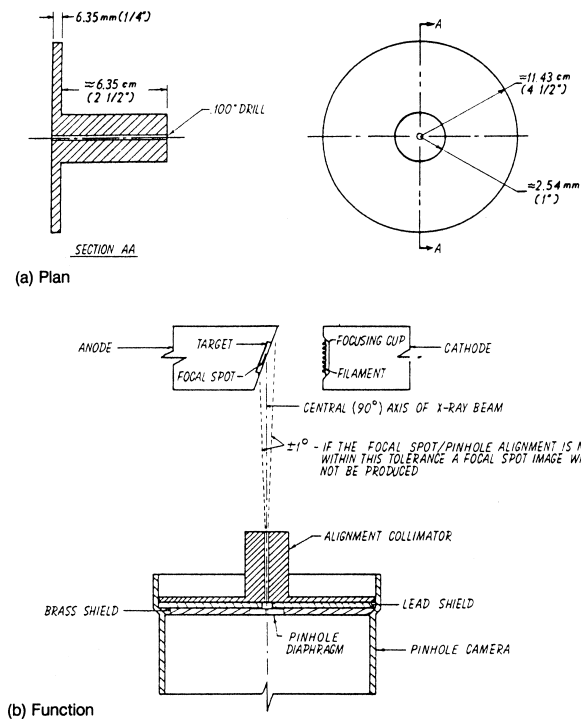


FIG. 7 ALIGNMENT COLLIMATOR

TABLE 3
TEST VOLTAGE AND CURRENT

kVp Rating of X-Ray Machine	Voltage To Be Used for Focal Spot Radiography	Current To Be Used for Focal Spot Radiography
≤75 kV	maximum rated voltage	
>75 kV to 150 kV	75 kV	50% of maximum permissible current at the test voltage utilized
>150 kV	50% of maximum rated voltage	

9. Precision and Bias

9.1 Conformance to the requirements specified herein will produce results that are within the following tolerances:

9.1.1 Technique — The technique requirements specified herein will produce a focal spot image whose size is $\pm 5\%$ of the actual effective focal spot size.

9.1.2 Measurement — The measurement requirements specified herein will produce results that are within the tolerances:

Nominal Focal Spot Size, mm (in.)	Measurement Tolerances
0.3 to 1.2 (0.011 to 0.046) incl	$\pm 30\%$
>1.2 to 2.5 (0.046 to 0.097) incl	$\pm 25\%$
>2.5 (0.097)	$\pm 20\%$

10. Keywords

10.1 focal spots; pinhole camera; pinhole imaging; x-ray; x-ray tube

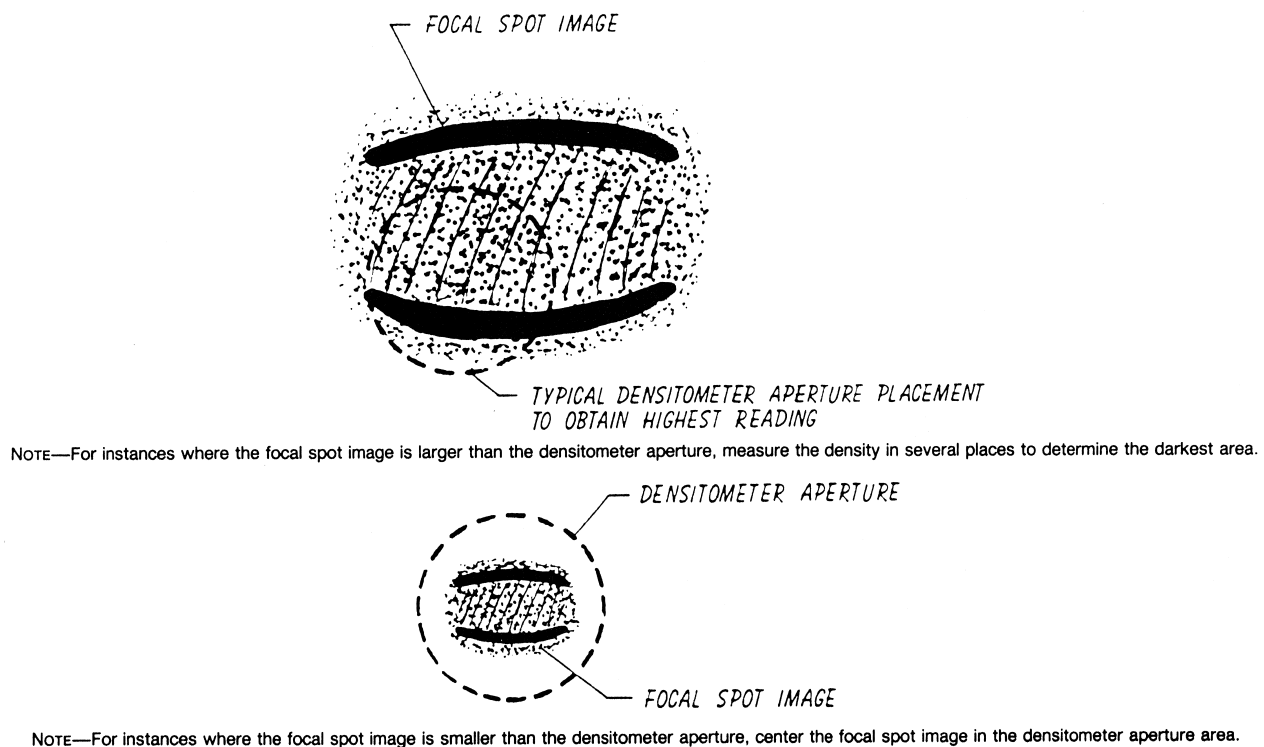


FIG. 8 FOCAL SPOT DENSITY MEASUREMENT

TABLE 4
DENSITY RANGE FOR DARKEST AREA OF FOCAL
SPOT IMAGE (See Fig. 7)

Transmission Densitometer Aperture Diameter, mm (in.)	For images whose minimum dimension is less than 2 mm (0.078 in.)	For images whose minimum dimension is greater than 2 mm (0.078 in.)
1 (0.039)	0.8 to 2.0 density	1.0 to 3.0 density
2 (0.078)	0.5 to 1.8 density	1.0 to 3.6 density

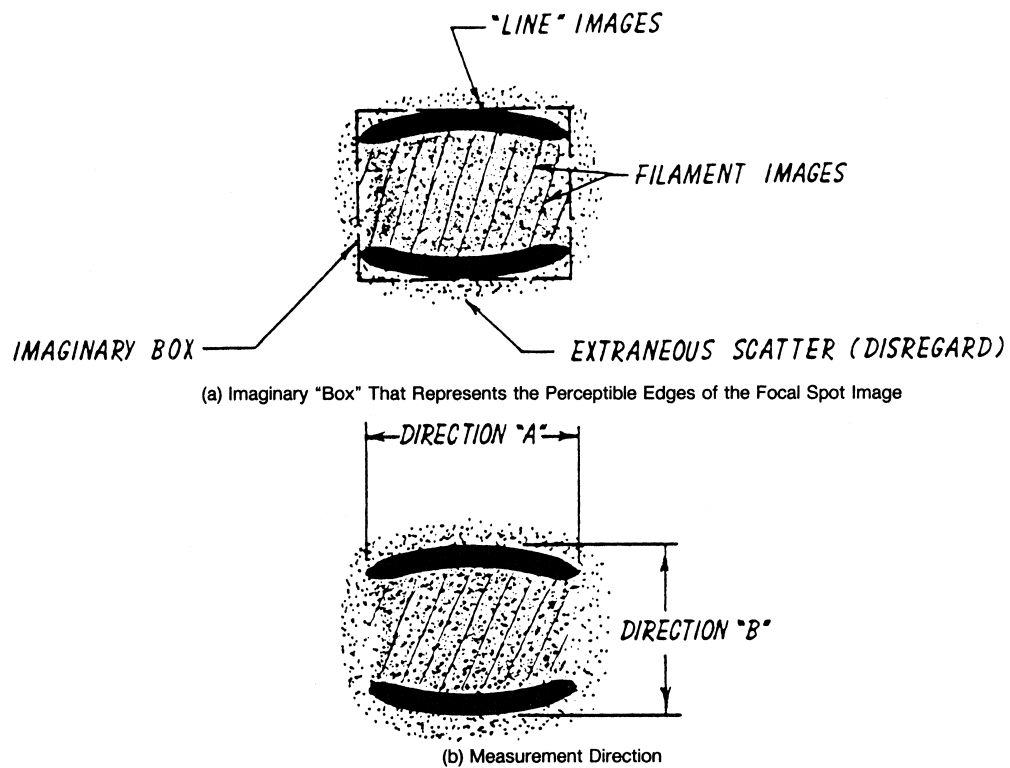


FIG. 9 FOCAL SPOT IMAGE

STANDARD PRACTICE FOR RADIOSCOPY



SE-1255



(Identical with ASTM Specification E 1255-96)

1. Scope

1.1 This practice provides application details for radioscopic examination using penetrating radiation. This includes dynamic radioscopy and for the purposes of this practice, radioscopy where there is no motion of the test object during exposure (referred to as static radioscopic imaging). Since the techniques involved and the applications for radioscopic examination are diverse, this practice is not intended to be limiting or restrictive, but rather to address the general applications of the technology and thereby facilitate its use. Refer to Guides E 94 and E 1000, Terminology E 1316, Practice E 747, Practice E 1025, and Fed. Std. Nos. 21 CFR 1020.40 and 29 CFR 1910.96 for a list of documents that provide additional information and guidance.

1.2 The general principles discussed in this practice apply broadly to penetrating radiation radioscopic systems. However, this document is written specifically for use with X-ray and gamma-ray systems. Other radioscopic systems, such as those employing neutrons, will involve equipment and application details unique to such systems.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific safety statements, see Section 8 and Fed. Std. Nos. 21 CFR 1020.40 and 29 CFR 1910.96.

2. Referenced Documents

2.1 ASTM Standards:

E 94 Guide for Radiographic Testing
E 747 Practice for Design, Manufacture, and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology

E 1000 Guide for Radioscopy

E 1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology

E 1316 Terminology for Nondestructive Examinations

2.2 ASNT Standard:

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing
ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 Federal Standards:

21 CFR 1020.40 Safety Requirements of Cabinet X-Ray Systems
29 CFR 1910.96 Ionizing Radiation

2.4 National Council on Radiation Protection and Measurement (NCRP) Standard:

NCRP 49 Structural Shielding Design and Evaluation for Medical Use of X-Rays and Gamma Rays of Energies up to 10 MeV

3. Summary of Practice

3.1 Manual evaluation as well as computer-aided automated radioscopic examination systems are used in a wide variety of penetrating radiation examination applications. A simple manual evaluation radioscopic examination system might consist of a radiation source and a directly viewed fluorescent screen, suitably enclosed in a radiation protective enclosure. At the other extreme, a complex automated radioscopic examination system might consist of an X-ray source, a robotic test part manipulator, a radiation protective enclosure, an electronic image detection system, a closed-circuit television image transmission system, a digital image processor, a video display, and a digital image archiving system. All system components are supervised by the host computer, which incorporates the software neces-

sary to not only operate the system components, but to make accept/reject decisions as well. Systems having a wide range of capabilities between these extremes can be assembled using available components. Guide E 1000 lists many different system configurations.

3.2 This practice provides details for applying radioscopic examination techniques, however, supplemental requirements are necessary to address areas that are application and performance specific. Annexes A1 and A2 provide the detailed supplemental requirements for government contracts (Annex A1) and nongovernment contracts (Annex A2).

4. Significance and Use

4.1 As with conventional radiography, radioscopic examination is broadly applicable to any material or test object through which a beam of penetrating radiation may be passed and detected including metals, plastics, ceramics, composite, and other nonmetallic materials. In addition to the benefits normally associated with radiography, radioscopic examination may be either a dynamic, filmless technique allowing the test part to be manipulated and imaging parameters optimized while the test object is undergoing examination, or a static, filmless technique wherein the test part is stationary with respect to the X-ray beam. Recent technology advances in the area of projection imaging, detectors, and digital image processing provide acceptable sensitivity for a wide range of applications.

5. Equipment and Procedure

5.1 System Configuration — Many different radioscopic examination system configurations are possible, and it is important to understand the advantages and limitations of each. It is important that the optimum radioscopic examination system be selected for each examination requirement through a careful analysis of the benefits and limitations of the available system components and the chosen system configuration. The provider as well as the user of the radioscopic examination services should be fully aware of the capabilities and limitations of the radioscopic examination system that is proposed for examination of the test object. The provider and the user of radioscopic examination services shall agree upon the system configuration to be used for each radioscopic examination application under consideration, and how its performance is to be evaluated.

5.1.1 The minimum radioscopic examination system configuration will include an appropriate source of penetrating radiation, a means for positioning the test object within the radiation beam, in the case of dynamic radioscopy, and a detection system. The system may be as simple as a directly viewed fluorescent screen with suitable radiation shielding for personnel protection that meets applicable radiation safety codes.

5.1.2 A more complex system might include the following components:

5.1.2.1 A microfocus X-ray system to facilitate high-resolution projection imaging;

5.1.2.2 A multiple axis test part manipulation system to provide dynamic, full volumetric test part manipulation under operator joystick or automated program control, for dynamic radioscopy;

5.1.2.3 An electronic imaging system to display a bright, two-dimensional gray-scale image of the test part at the operator's control console;

5.1.2.4 A digital image processing system to perform image enhancement and image evaluation functions;

5.1.2.5 An archival quality image recording system; and

5.1.2.6 A radiation protective enclosure with appropriate safety interlocks and a radiation warning system.

5.1.3 Whether a simple or a complex system is used, the system components and configuration utilized to achieve the prescribed test results must be carefully selected.

5.2 Practice:

5.2.1 The purchaser and supplier for radioscopic examination services shall mutually agree upon a written procedure using the applicable annex of supplemental requirements and also consider the following general requirements.

5.2.1.1 Equipment Qualifications — A listing of the system features that must be qualified to ensure that the system is capable of performing the desired radioscopic examination task.

5.2.1.2 Test Object Scan Plan — A listing of test object orientations, ranges of motions, and manipulation speeds through which the test object must be manipulated to ensure satisfactory examination.

5.2.1.3 Radioscopic Parameters — A listing of all the radiation source–related variables that can affect the examination outcome for the selected system configuration such as: source energy, intensity, focal spot size, range of source to object distances, range of object to image plane distances, and source to image plane distances.

5.2.1.4 Image Processing Parameters — A listing of all the image processing variables necessary to enhance fine detail detectability in the test object and to achieve the required sensitivity level. These would include, but are not limited to, techniques such as noise reduction, contrast enhancement, and spatial filtering. Great care should be exercised in the selection of directional image processing parameters such as spatial filtering, which may emphasize features in certain orientations and suppress them in others. The listing should indicate the means for qualifying image processing parameters.

5.2.1.5 Image Display Parameters — A listing of the techniques and the intervals at which they are to be applied for standardizing the video image display as to brightness, contrast, focus, and linearity.

5.2.1.6 Accept/Reject Criteria — A listing of the expected kinds of test object imperfections and the rejection level for each.

5.2.1.7 Performance Evaluation — A listing of the qualification tests and the intervals at which they are to be applied to ensure that the radioscopic examination system is suitable for its intended purpose.

5.2.1.8 Image Archiving Requirements — A listing of the requirements, if any, for preserving a historical record of the examination results. The listing may include examination images along with written or electronically recorded alpha-numeric or audio narrative information, or both, sufficient to allow subsequent reevaluation or repetition of the radioscopic examination.

5.2.1.9 Operator Qualifications — Nondestructive testing (NDT) personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or a standard such as ANSI/ASNT CP-189, SNT-TC-1A, MIL-STD-410, or a similar document, to the level appropriate for the performance of the listed radioscopic examination.

6. Radioscopic Examination System Performance Considerations and Measurement

6.1 Factors Affecting System Performance — Total radioscopic examination system performance is determined by the combined performance of the system components, which include the radiation source, manipulation system (for dynamic radioscopy), detection system, information processing system, image display, automatic evaluation system, and examination record archiving system.

6.1.1 Radiation Sources — While the radioscopic examination systems may utilize either radioisotope or X-ray sources, X-radiation, is used for most radioscopic examination applications. This is due to the energy spectrum of the X-radiation, which contains a blend of contrast-enhancing longer wavelengths, as well as the more penetrating, shorter wavelengths. X-radiation is adjustable in energy and intensity to meet the radioscopic examination test requirements, and has the added safety feature of discontinued radiation production when switched off. A radioisotope source has the advantages of small physical size, portability, simplicity, and uniformity of output.

6.1.1.1 X-ray machines produce a more intense X-ray beam emanating from a smaller focal spot than do radioisotope sources. X-ray focal spot sizes range from a few millimeters down to a few micrometers. Reducing the source size reduces geometric unsharpness, thereby enhancing detail sensitivity. X-ray sources may offer multiple or variable focal spot sizes. Smaller focal spots produce higher resolution and provide reduced X-ray beam intensity, while larger focal spots provide higher X-ray intensity and produce lower resolution. Microfocus X-ray tubes are available with focal spots that may be adjusted to as small as a few micrometers in diameter, while still producing an X-ray beam of sufficient intensity so as to be useful for the radioscopic examination of finely detailed test objects.

6.1.1.2 Conventional focal spots of 1.0 mm and larger are useful at low geometric magnification values close to 1 $\times$. Fractional focal spots ranging from 0.4 mm up to 1.0 mm are useful at geometric magnifications of up to approximately 2 $\times$. Minifocus spots in the range from 0.1 mm up to 0.4 mm are useful at geometric magnifications up to about 6 $\times$. Greater magnifications suggest the use of a microfocus spot size of less than 0.1 mm in order to minimize the effects of geometric unsharpness. Microfocus X-ray tubes are capable of focal spot sizes of less than 10 micrometers (10⁻⁸

meters) and are useful for geometric magnifications of more than 100×.

6.1.2 Manipulation System for Dynamic Radioscopy — The test part manipulation system has the function of holding the test object and providing the necessary degrees of freedom, ranges of motion, and speeds of travel to position the test object areas of interest in the radiation beam in such a way so as to maximize the radioscopy examination system's response. In some applications it may be desirable to manipulate the radiation source and detection system instead of, or in addition to, the test object. The manipulation system must be capable of smooth well-controlled motion, especially so for high-magnification microfocus techniques, to take full advantage of the dynamic aspects of the radioscopy examination.

6.1.3 Detection System — The detection system is a key element. It has the function of converting the radiation input signal containing test part information, into a corresponding optical or electronic output signal while preserving the maximum amount of test object information. The detector may be of one-dimensional design, providing test part information one line at a time, or may be a two-dimensional area detector providing an area field of view.

6.1.4 Information Processing of System:

6.1.4.1 The function of the information processing system is to take the output of the detection system and present a useful image for display and operator interpretation, or for automatic evaluation. The information processing system may take many different forms, and may process analog or digital information, or a combination of the two.

6.1.4.2 The information processing system includes all of the optics, electronics, and interfaces after the detection system to and including the image display and automatic evaluation system. Information system components include such devices as lenses, fiber optic couplings, light amplifiers, video cameras, image processors, and in general any device that processes radioscopy examination information after the detection system.

6.1.4.3 The digital image processing system warrants special attention, since it is the means by which radioscopy examination information may be enhanced. Great care must be exercised in determining which image processing techniques are most beneficial for the particular application. Directional spatial filtering operations, for example, must be given special attention

as certain feature orientations are emphasized while others are suppressed. While many digital image processing operations occur sufficiently fast to follow time-dependent radioscopy system variables, others do not. Some image processing operations require significant image acquisition and processing time, so as to limit the dynamic response of the radioscopy exam, in dynamic radioscopy systems.

6.1.5 Automatic Evaluation System — Some radioscopy examination applications can be fully automated including the accept/reject decision through computer techniques. The automatic evaluation system's response to various test object conditions must be carefully determined under actual operating conditions. The potential for rejecting good test objects and accepting defective test objects must be considered. Automatic evaluation system performance criteria should be mutually determined by the provider and user of radioscopy examination services.

6.1.6 Image Display:

6.1.6.1 The function of the image display is to convey radioscopy information about the test object to the system operator. For manual evaluation systems, the displayed image is used as the basis for accepting or rejecting the test object, subject to the operator's interpretation of the radioscopy image. The image display performance, size, and placement are important radioscopy system considerations.

6.1.6.2 When employing a television image presentation, vertical and horizontal resolution are often not the same. Therefore, the effect of raster orientation upon the radioscopy examination system's ability to detect fine detail, regardless of orientation, must be taken into account.

6.1.7 Radioscopy Examination Record Archiving System — Many radioscopy examination applications require an archival quality examination record of the radioscopy examination. The archiving system may take many forms, a few of which are listed in 6.1.7.1 through 6.1.7.11. Each archiving system has its own peculiarities as to image quality, archival storage properties, equipment, and media cost. The examination record archiving system should be chosen on the basis of these and other pertinent parameters, as agreed upon by the provider and user of radioscopy examination services. The reproduction quality of the archival method should be sufficient to demonstrate the same image quality as was used to qualify the radioscopy examination system.

6.1.7.1 Film or paper radiograph of the test object made under the same conditions as the radioscopy examination image;

6.1.7.2 Spot film camera used to photograph the examination image directly from the output of an X-ray image intensifier without the intervening television chain limitations;

6.1.7.3 Photograph of the actual image display;

6.1.7.4 Multiformat camera used to make a photograph of the examination image from the video signal;

6.1.7.5 Video hard copy device used to create a paper facsimile image from the video signal;

6.1.7.6 Laser print hard copy device used to create a film image from the scanned detector output;

6.1.7.7 Video tape recorder used to record the video signal on magnetic tape; characterized by long recording time at video frame rates; useful for capturing test part motion;

6.1.7.8 Digital recording on magnetic disk or tape used to store the image of the test object digitally, characterized by limited storage capacity at video frame rates, therefore limiting the ability to capture test part motion in dynamic radioscopy systems;

6.1.7.9 Digital recording on optical disk used to store the image of the test object digitally; offers larger storage capacity than magnetic disk or tape; consideration should be given to the type of optical storage because there are fundamentally two different types: magneto-optical where radiological data can be erased or altered, and write once read many times (WORM) where a common format is CD-ROM and the radiological data cannot be erased or altered after the disk is created.

6.1.7.10 Electronic digital memory such as ROM (read only memory) or EPROM (erasable programmable read only memory), characterized by relatively limited capacity; and

6.1.7.11 Hologram used to store high-density digital image data on film at high-information density.

6.1.8 Examination Record Data — The examination record should contain sufficient information to allow the radioscopy examination test to be reevaluated or duplicated. Examination record data should be recorded contemporaneously with the radioscopy examina-

tion image, and may be in writing or a voice narrative, providing the following minimum data:

6.1.8.1 Radioscopy examination system designation, test date, operator identification, operating turn or shift, and other pertinent test and customer data;

6.1.8.2 Specific test part data as to part number, batch, serial number, etc. (as applicable);

6.1.8.3 Test part orientation and examination site information by manipulation system coordinate data or by reference to unique test part features within the field of view; and

6.1.8.4 System performance monitoring by recording the results of the prescribed radioscopy examination system performance monitoring tests, as set forth in Section 5, at the beginning and end of a series of radioscopy examinations, not to exceed the interval set forth in 6.2.1 for system performance monitoring.

6.2 Performance Measurement — Radioscopy examination system performance parameters must be determined initially and monitored regularly to ensure consistent results. The best measure of total radioscopy examination system performance can be made with the system in operation, utilizing a test object similar to the test part under actual operating conditions. This indicates the use of an actual or simulated test object or calibration block containing actual or simulated features that must be reliably detected. Such a calibration block will provide a reliable indication of the radioscopy examination system's capabilities. Conventional wire- or plaque-type IQIs may be used in place of, or in addition to, the simulated test object or calibration block. Performance measurement methods are a matter of agreement between the provider and user of radioscopy examination services.

6.2.1 Performance Measurement Intervals — System performance measurement techniques should be standardized so that performance measurement tests may be readily duplicated at specified intervals. Radioscopy examination system performance should be evaluated at sufficiently frequent intervals, as may be agreed upon by the supplier and user of radioscopy examination services, to minimize the possibility of time-dependent performance variations.

6.2.2 Measurement With IQIs — Radioscopy examination system performance measurement using IQIs shall be in accordance with accepted industry standards describing the use of IQIs. The IQIs should be placed on the test object as close as possible to the region of interest. The use of wire-type IQIs should also take

into account the fact that the radioscopic examination system may exhibit asymmetrical sensitivity, in which case the wire diameter axis shall be oriented along the system's axis of least sensitivity. Selection of IQI thickness should be consistent with the test part radiation path length thickness.

6.2.3 Measurement With a Calibration Block —

The calibration block may be an actual test object with known features that are representative of the range of features to be detected, or may be fabricated to simulate the test object with a suitable range of representative features. Alternatively, the calibration block may be a one-of-a-kind or few-of-a-kind reference test object containing known imperfections that have been verified independently. Calibration blocks containing known, natural defects are useful on a single-task basis, but are not universally applicable. Where standardization among two or more radioscopic examination systems is required, a duplicate manufactured calibration block should be used. The calibration blocks should approximate the test object as closely as is practical, being made of the same material with similar dimensions and features in the radioscopic examination region of interest. Manufactured calibration blocks should include features at least as small as those that must be reliably detected in the actual test objects in locations where they are expected to occur in the actual test object. Where features are internal to the test object, it is permissible to produce the calibration block in sections. Calibration block details are a matter of agreement between the user and supplier of radioscopic examination services.

6.2.3.1 Use of a Calibration Block — The calibration block should be placed into the radioscopic examination system in the same position as the actual test object and may be manipulated through the same range of motions through a given exposure for dynamic radioscopic systems as are available for the actual test object, so as to maximize the radioscopic examination system's response to the simulated imperfection.

6.2.3.2 Radioscopic Examination Techniques — (radiation beam energy, intensity, focal spot size, enlargement, digital image processing parameters, manipulation scan plan for dynamic radioscopic systems, scanning speed, and other system variables) utilized for the calibration block shall be identical to those used for the actual examination of the test object.

6.2.4 Use of Calibrated Line Pair Test Pattern and Step Wedge:

6.2.4.1 A calibrated line pair test pattern and step wedge may be used, if so desired, to determine and track radioscopic system performance in terms of spatial resolution and contrast sensitivity. The line pair test pattern is used without an additional absorber to evaluate system spatial resolution. The step wedge is used to evaluate system contrast sensitivity.

6.2.4.2 The step wedge must be made of the same material as the test part with steps representing 100%, 99%, 98%, and 97% of both the thickest and the thinnest material sections to be examined. The thinner steps shall be contiguous to their respective 100% section thicknesses in order to facilitate discerning the minimum visible thickness step. Other thickness steps are permissible upon agreement between the provider and the user of radioscopic services.

6.2.4.3 The line pair test pattern and the step wedge tests shall be conducted in a manner similar to the performance measurements for the IQI or the calibration block set forth in 6.2.2 and 6.2.3. It is permissible to adjust the X-ray energy and intensity to obtain a usable line pair test pattern image brightness. In the case of a radioisotope or X-ray generating system where the energy or intensity may not be adjusted, additional filtration may be added at the radiation source to reduce the brightness to a useful level. Contrast sensitivity shall be evaluated at the same energy and intensity levels as are used for the radioscopic technique.

6.2.4.4 A system that exhibits a spatial resolution of 3 line pairs/mm, a thin section contrast sensitivity of 3%, and a thick section contrast sensitivity of 2% may be said to have an equivalent performance level of 3%–2%–3 lp/mm.

6.2.4.5 The line pair test pattern and the step wedge may be used to make more frequent periodic system performance checks than required in accordance with 6.2.1. Resolution and contrast sensitivity checks must be correlated with IQI or calibration block performance measurements. This may be done by first evaluating system measurement in accordance with 6.2.2 or 6.2.3 and immediately thereafter determining the equivalent spatial resolution and contrast sensitivity values.

6.2.5 Importance of Proper Environmental Conditions — Environmental conditions conducive to human comfort and concentration will promote examination efficiency and reliability, and must be considered in the performance of manual evaluation radioscopic examination systems. A proper examination environment will take into account temperature, humidity, dust, lighting,

access, and noise level factors. Proper reduced lighting intensity is extremely important to provide for high-contrast glare-free viewing of radioscopic examination images.

7. Radioscopic Examination Interpretation and Acceptance Criteria

7.1 Interpretation — Interpretation may be done either by an operator in a manual evaluation radioscopic environment, or by means of a computer and appropriate software in the case of an automated radioscopic examination system. A hybrid environment may also be utilized whereby the computer and software present to the operator a recommended interpretation, which is then subject to the operator's final disposition.

7.2 Operator — The supplier and user should reach an agreement as to operator qualifications including duty and rest periods. Recommended Practice SNT-TC-1A sets forth three levels of nondestructive testing personnel qualifications that the radioscopic examination practitioner may find useful.

7.3 Accept/Reject Criteria — Accept/reject criteria are a matter of contractual agreement between the

provider and the user of radioscopic examination services.

8. Records, Reports, and Identification of Accepted Material

8.1 Records and reports are a matter of agreement between the supplier and the user. If an examination record archiving requirement exists, refer to 6.1.8, which outlines the necessary information that should be a part of an archival examination record.

9. Safety Conditions

9.1 Radioscopic examination procedures shall be carried out under protective conditions so that personnel will not receive radiation dose levels exceeding that permitted by company, city, state, or national regulations. The recommendations of the National Committee on Radiation Protection should be the guide to radiation safety.

10. Keywords

10.1 analog; detector; digital; display; examination; image; manipulator; processor; radioscopic; source

ANNEXES

(Mandatory Information)

A1. DEPARTMENT OF DEFENSE CONTRACTS, SUPPLEMENTAL REQUIREMENTS

A1.1 Scope

A1.1.1 Purpose — This annex is to be used in conjunction with Practice E 1255 and MIL-STD-453. It permits the use of and gives guidance on the implementation of radioscopic examination for materials, components, and assemblies, when specified in the contract documents. The radioscopic requirements described herein allow the use of radioscopy for new applications as well as to replace radiography when inspection coverage, greater throughput, or improved inspection economics can be obtained, provided a satisfactory level of image quality can be demonstrated.

A1.1.2 Application — This annex provides guidelines for a written practice as required in 3.2 and 5.2.1 of Practice E 1255. Should the requirements in this annex conflict with any other requirements of Practice E 1255, then Annex A1 takes precedence. The requirements of this annex are intended to control the quality of the radioscopic examination and not to specify the accept/reject criteria for the test object. Accept/reject criteria are provided in other contract documents.

A1.2 Referenced Documents

A1.2.1 In addition to those documents referenced in Practice E 1255, the following standards are applicable to the extent specified herein.

A1.2.2 ASTM Standards:

E 1411 Practice for Qualification of Radiographic Systems

E 1453 Guide for Storage of Media That Contains Analog or Digital Radiographic Data

A1.2.3 Military Standards:

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification

MIL-STD-453 Inspection, Radiographic

DOD-STD-2167 Defense System Software Development

A1.2.4 American Welding Society Standard:
ANSI/AWS 3.0 Welding Terms and Definitions

A1.2.5 Government Standards — Unless otherwise stated, the issues of these documents are those listed in the Defense Index of Specifications and Standards (DODISS) and supplement thereto, cited in the contract document.

A1.2.6 Order of Preference — In the event of conflict between the text of this document and the references listed in A1.2.2, this document shall take precedence. However, nothing in this document shall supersede applicable laws and regulations unless a specific exemption has been obtained from the cognizant authorities.

A1.3 Terminology

A1.3.1 component — the test part or parts described, assembled, or processed to the extent specified by the drawing.

A1.3.2 contracting agency — a prime contractor, subcontractor, or government agency that procures radioscopic examination services.

A1.3.3 contract documents — the procuring contract and all drawings, specifications, standards, and other information included with or referred to by the procuring contract.

A1.3.4 mandatory radioscopic examination — those radioscopic examinations which are a part of the required radiographic examinations specified in the contract documents.

A1.3.5 NDT facility — the organization that is responsible for the providing of nondestructive examination services.

A1.3.6 optional radioscopic examination — those radioscopic examinations which are conducted for process verification or information only and are not a part of the required radiographic examination specified in the contract documents.

A1.3.7 prime contractor — a contractor having responsibility for the design control and delivery to the department of defense for system/equipment such as aircraft, engines, ships, tanks, vehicles, guns and missiles, ground communications and electronic systems, ground support, and test equipment.

A1.3.8 test object — the material, component or assembly that is the subject of the radioscopic examination.

A1.3.9 written procedure — in radioscopy, a series of steps that are to be followed in a regular definite order. The radioscopic system operator follows the written procedure to consistently obtain the desired results and image quality level when performing radioscopic examination. The development of a radioscopic technique usually precedes the preparation of a written procedure.

A1.3.10 Other definitions not given herein shall be as specified in Terminology E 1316.

A1.4 General Requirements

A1.4.1 Equipment Qualification — Radioscopic system qualification shall be in accordance with Practice E 1411 and can best be evaluated with IQIs similar to the flaw type being investigated. A common IQI is described in MIL-STD-453.

A1.4.2 Personnel Qualification — Radioscopic personnel shall be qualified and certified in accordance with the general requirements of MIL-STD-410, until specific requirements for radioscopy are included. Radioscopic system qualification, the development of radioscopic examination test techniques, scan plans, and the overall implementation of radioscopic examination in accordance with this annex, shall be under the control and supervision of a qualified MIL-STD-410 Level III with additional radioscopy training and experience or in conjunction with an individual having the necessary training and experience in radioscopic examination.

A1.4.3 Safety — The performance or radioscopic examination shall present no hazards to the safety of personnel or property. Applicable Federal, state, and local radiation safety codes shall be adhered to. All radioscopic procedures shall be performed in a safe manner, such that personnel in that area are not exposed to any radiation dosage and shall in no case exceed Federal, state, and local limits.

A1.4.4 Archival Recording of Mandatory Radioscopic Examination — When required by contractual agreement, the radioscopic examination record shall contain the results of mandatory radioscopic examination.

tions. The radioscopic examination record shall be suitably archived for a period of time not less than five years from the examination date or as may otherwise be required in the contract documents. Efficient radioscopic examination record recall shall be available at any time over the record retention period. The radioscopic examination record shall be traceable to the test object (by serial number or other means) or to the batch or lot number, if tested in groups. Mandatory radioscopic examinations shall be specified in the contract documents. The optional radioscopic examinations are not specified in the contract documents.

A1.4.4.1 Radioscopic Examination Record — The recorded radioscopic examination record for mandatory examinations shall include the written results of the radioscopic examination and the radioscopic image, if an image is utilized in the accept/reject decision-making process. The recorded radioscopic image shall be provided with such additional information as may be required to allow the subsequent off-line review of the radioscopic examination results and, if necessary, the repeating of the radioscopic examination.

A1.4.4.2 Image Recording Media — The radioscopic image shall be recorded on a media that is appropriate to the radioscopic examination requirement. The recorded image shall reference the examination zones in such a way that the reviewer can confirm that all zones have been covered. The recorded radioscopic image shall provide an image quality at least equal to that for which the radioscopic system is qualified. The recording media shall be capable of maintaining the required image quality for the required record storage period or not less than five years from the recording date. The radioscopic image record shall be maintained in an operable condition for the duration of the record storage period, measured from the date when the last radioscopic image was recorded.

A1.4.4.3 Recording Media Storage Conditions — Media storage and handling shall be in accordance with Guide E 1453.

A1.4.5 Image Quality Indicators — Image quality indicators must be chosen with care to demonstrate the radioscopic system's ability to detect discontinuities or other features that are of interest. MIL-STD-453, Practice E 1025 plaque-type, and Practice E 747 wire-type IQIs and calibration blocks with real or simulated defects, to match the application, are all acceptable unless a particular IQI is specified in the contract documents. The selected IQI or calibration block shall be detailed in the written procedure. An IQI or calibration

block may not be required for the following radioscopic examinations:

A1.4.5.1 When conducting radioscopy to check for adequate defect removal or grind-out, the final acceptance radioscopic examination shall include an IQI;

A1.4.5.2 Examinations to show material details or contrast between two or more dissimilar materials, in component parts or assemblies, including honeycomb areas for the detection of fabrication irregularities or the presence or absence of material;

A1.4.5.3 Examinations of electronic components for contamination, loose or missing elements, solder balls, broken or misplaced wires or connectors, and potted assemblies for broken internal components or missing potting compound;

A1.4.5.4 Optional radioscopic examinations; and

A1.4.5.5 Where the use of an IQI is impractical or ineffective, an alternate method may be used, subject to the approval of the contracting agency.

A1.4.6 Classification of Test Object Zones for Radioscopy — The classification of test objects into zones for various accept/reject criteria shall be determined from the contract documents.

A1.5 Detailed Requirements

A1.5.1 Application Qualification:

A1.5.1.1 New Applications — Radioscopy may be used where appropriate for new examination requirements, provided the required performance, including image quality, can be met.

A1.5.1.2 Replacement of Existing Radiographic Applications — When agreed to by the contracting officer, radioscopy may be used to replace or augment existing radiographic applications, provided that the radioscopic results correlate favorably with the results obtained with X-ray film produced in accordance with MIL-STD-453. Favorable correlation means that the radioscopic and film images show similar sensitivity to test object features that are of interest.

A1.5.2 Written Procedure — It shall be the responsibility of the NDE facility to develop a written radioscopic examination procedure to ensure the effective and repeatable radioscopic examination of the test object. A test object scan plan for dynamic radioscopic systems, meeting the requirements of Practice E 1255 (see 5.2.1.2), shall be included in the written procedure. Those portions of the contract document that specify

and detail radioscopic examination shall become an appendix to the written procedure. The written procedure must be approved by the Level III of the NDE facility. Where required, the written procedure shall be approved by the contracting agency prior to use. The written procedure shall include as a minimum the following information:

A1.5.2.1 A drawing, sketch, or photograph of the component that shows the radiation beam axis, positions(s) of the detector, and applicable IQI for each and all variations of the test object orientation and beam energy. This requirement may be expressed in coordinates for automated systems having calibrated manipulation systems;

A1.5.2.2 A physical description of the test object, including size, thickness, weight, and composition;

A1.5.2.3 Classification of the test object into zones for radioscopy;

A1.5.2.4 Test part masking, if used, for each required view;

A1.5.2.5 Added radiation source collimation, expressed in terms of the radiation field dimensions at the test object source side, for each required view;

A1.5.2.6 Detector field of view for each required view;

A1.5.2.7 Detector diaphragm settings, expressed in terms of field of view at the detector, for each required view;

A1.5.2.8 The allowable range of radiation energy and beam current or source intensity and the focal spot or source size for each required view;

A1.5.2.9 Added beam filtration, if used, for each required view;

A1.5.2.10 The inspection geometry and coverage for each required view;

A1.5.2.11 Type of IQI or calibration block used and the required quality level;

A1.5.2.12 All hardware and software settings that can be changed by the operator to affect the outcome of the radioscopic examination. Such settings include, but are not limited to, video camera and display settings and image processor variables; and

A1.5.2.13 The recording media and storage image format for mandatory radioscopic image storage.

A1.5.3 Test Object Examination — The number of test objects to be examined and the coverage required for each test object shall be specified in the contract documents. If not specified, all test objects shall receive 100% radioscopic coverage as detailed in the written procedure.

A1.5.4 Image Quality — Unless otherwise specified in the contract documents, the required image quality level is 2-2T. Image quality assessment shall be performed using the same system parameters as in the inspection and as documented in the written procedure.

A1.5.4.1 The IQI may be placed on the test object or on a mounting block, at or near the test object location, following the requirements of MIL-STD-453. In the case of small radioscopic fields of view or other situations where it is not practical to place the IQI in the field of view with the test object and maintain it normal to the X-ray beam, the IQI may be imaged immediately before and after the test object examination. Batch quantities of similar parts need not have IQI images made between each part, at the discretion of the Level III. The radioscopic examination results shall be invalid, if the before and after IQI images fail to demonstrate the required sensitivity. The before and after IQI images shall be considered a part of the test object image for radioscopic image interpretation and archiving purposes.

A1.5.4.2 With written permission from the contracting agency, other IQIs or a calibration block with natural or artificial flaws may be used instead of the specified IQI.

A1.5.5 Radioscopic System Qualification — The radioscopic system, including mandatory radioscopic image archiving devices, shall be qualified to the image quality level required for test object examination. Radioscopic system initial qualification shall be in accordance with Practice E 1411.

A1.5.6 Radioscopic System Requalification — The radioscopic system, including mandatory image archiving devices, shall be periodically requalified at intervals frequent enough to ensure the required level of radioscopic system performance. Each requalification shall be carried out in accordance with Practice E 1411.

A1.5.7 Inspection Image Control — The radioscopic system shall be checked for performance before each day's production usage using the method and devices that were initially used to qualify the written procedure. A log shall be maintained to document any changes in system performance requiring changes in

operating parameters and listing all equipment maintenance. System requalification shall be required whenever image quality requirements can no longer be met.

A1.5.8 Repair of Radioscopic System — Repair or replacement of key radioscopic system components including, but not limited to, the radiation source, image forming, image transmission, image processing, and image display subsystems shall be cause for system requalification. In no case shall the interval between qualification tests exceed one year. The qualification statement shall be posted on the radioscopic system. The results of the qualification tests shall be maintained in the radioscopic system equipment file until the completion of the next qualification procedure or the expiration of the archival image retention period, whichever is longer.

A1.5.9 Image Interpretation:

A1.5.9.1 Static Imaging — Radioscopic system qualification in accordance with Practice E 1411 applies to static imaging conditions only where the test part is stationary with respect to the X-ray beam. Therefore, all performance measurements are based upon static image quality. All mandatory radioscopic examination accept/reject decisions shall be based upon the assessment of static images.

A1.5.9.2 Dynamic Imaging — Dynamic or in-motion imaging may be used to gain useful information about the test object. However, unless dynamic imaging is specified, the final assessment of image formation for mandatory radioscopic examinations shall be made in the static mode. When the contracting agency specifies dynamic inspection, all aspects of the procedure must be approved by MIL-STD-410 Level III personnel. For dynamic inspection, the image quality shall be measured under the same procedure as the inspection.

A1.5.10 Feature Size Determination — Where feature measurement from the radioscopic image is required, the written procedure shall include methodology for determining and maintaining the accuracy of the selected measurement method.

A1.5.10.1 Feature Measurement by Test Object Displacement — For those radioscopic systems with calibrated manipulation systems, the more accurate, and therefore preferred, method of measurement is to manipulate the extremities of the feature to be measured to a common central reference point within the radioscopic image field of view. The dimension may then be read from the manipulation system position display.

A1.5.10.2 Feature Measurement by Comparison — A second method involves comparing the test object feature with a known, observable dimension which must be wholly within the radioscopic field of view. Many digital image processors facilitate this type of measurement by counting pixels over the feature length. The pixel number is often converted to engineering units by comparison with a known length. However, the orientation and position along the X-ray beam (magnification) of both the feature and the calibrating reference length affect the accuracy of such measurements.

A1.5.11 Gray Scale Range — The gray scale range required to meet initial qualification contrast sensitivity requirements for image quality shall be recorded and monitored. For systems using human image assessment, it is particularly important that the gray scale range and the number of gray scale steps be closely matched to the response of the human eye. The written procedure shall include a means for monitoring the required gray scale range using a contrast sensitivity gage, step wedge, or similar device made of the test object or IQI material.

A1.5.12 Timing of Radioscopic Examination — Radioscopic examination shall be performed at the time of manufacturing, assembly, or rework as required by the contract documents.

A1.5.13 Identification — A means shall be provided for the positive identification of the test object to the archival radioscopic inspection record. Archived radioscopic images shall be annotated to agree with the test object identification.

A1.5.14 Locating the Radioscopic Examination Areas — Whenever more than one image is required for a weldment or other test object, location markers shall be placed on the test object in order that the orientation of the test object and the location of test object features relative to the radioscopic field of view may be established. This requirement shall not apply to automated systems having programmed radioscopic examination sequences where coverage has been proven during the development of the scan plan. Also, this requirement does not apply to the radioscopic examination of simple or small shapes where the test part orientation is obvious and coverage is not in question.

A1.5.15 Surface Preparation — Test objects may be inspected without surface preparation, except when required to remove surface conditions that may interfere with proper interpretation of the radioscopic image or that may create a safety hazard.

A1.5.16 Detailed Data — The provider of radioscopy examination services shall keep the written procedure, qualification documentation, and the signed inspection reports or tabulated results, or both, for five years from the radioscopy examination date, unless otherwise specified in the contract documents. For software-based automated radioscopy systems using custom software, a copy of the source code and the related inspection parameters shall also be maintained on file for a like period of time. This requirement shall not apply to standard commercially available software packages or to traceable software documentation which complies with DOD-STD-2167 where a separate copy of the software is maintained.

A1.5.17 Radioscopic Reexamination of Repairs — When repair has been performed as the result of radioscopy examination, the repaired areas shall be reexamined using the same radioscopy technique to evaluate the effectiveness of the repair. Each repaired area shall be identified with R1, R2, R3, and so forth, to indicate the number of times repair was performed.

A1.5.18 Retention of Radioscopic Examination Records — Mandatory radioscopy examination records and associated radioscopy images shall be stored in a proper repository at the contractor's plant for five years from the date from which they were made. Special instructions, such as storage for other periods of time, making backup copies, copying the records to other media, or having the records destroyed shall be specified in the contract documents.

A1.5.19 Rejection of Test Objects — Test objects containing defects exceeding the permissible limits specified in the contract documents shall be separated from acceptable material, appropriately identified as discrepant, and submitted for material review when required by the contract documents.

A1.5.20 Reexamination — When there is a reasonable doubt as to the ability to interpret the radioscopy results because of improper execution or equipment malfunction, the test object shall be reexamined using the correct procedure. If the problem is not resolved by reexamination, the procedure shall be reviewed by the Level III of the NDE facility and adjusted, if necessary. Reference exposures may be made using radiography if necessary. If the reexamination was caused by equipment malfunction, the equipment may not be returned to service until the malfunction is repaired and the equipment is requalified to the current qualification requirements in accordance with Practice E 1411.

A1.5.21 Test Object Marking — The marking of test objects shall be as specified in MIL-STD-453.

A1.6 Notes

A1.6.1 This section contains information of a general or explanatory nature and is not mandatory.

A1.6.1.1 Caution — Active electronic components and some materials, such as tetrafluoroethylene, are subject to radiation damage if exposed to large doses of radiation. While normal radioscopy examinations should cause no problem, extended periods of radiation exposure should be avoided.

A1.6.1.2 Human Factors — The success of radioscopy examinations which involve human image interpretation are, like radiography, subject to human factors. Careful attention should be given to the human environment where image interpretation takes place, to make it as conducive to correct, consistent image interpretation as possible. Measures should also be implemented to ensure that fatigue does not interfere with correct and consistent radioscopy image interpretation.

A1.6.1.3 Use of IQI(s) — As with radiography, the achievement of the required IQI sensitivity does not guarantee the ability to find all defects down to the minimum defect size. This is due to the fact that many defects, especially those of a planar nature, are very orientation sensitive. When using dynamic radioscopy systems, care must be taken to see that the scan plan includes sufficient manipulations to maximize the possibility that orientation-sensitive defects will be found. It is for this reason that the use of calibration blocks with real or simulated defects may more accurately characterize the ability of the radioscopy system to find orientation-sensitive defects when using dynamic radioscopy systems.

A1.6.1.4 Use of Image-Processing Techniques — Care should be exercised in applying digital image-processing techniques to evaluate the overall effect upon image quality. For example, contrast enhancement techniques may emphasize contrast in one brightness range, while decreasing contrast in other brightness ranges. Some spatial filters have directional aspects, whereby features in one direction are emphasized while those in the orthogonal direction are deemphasized. Such cautions are intended to cause the careful evaluation of digital image-processing techniques and not to discourage their use.

A1.6.1.5 Feature Size Determination — As with radiography, great care must be exercised in trying to assess test part feature dimensions from a two-dimensional projected view.

A2. NONGOVERNMENT CONTRACT SUPPLEMENTAL REQUIREMENTS

A2.1 Scope

A2.1.1 Purpose — This annex is to be used in conjunction with Practice E 1255. This annex includes application-specific details as may be agreed upon by the purchaser and the supplier of radioscopy examination services.

A2.1.2 Application — This document satisfies the requirements of 3.2 and 5.2.1 of Practice E 1255. Should this annex conflict with any other requirements of Practice E 1255, this annex shall prevail. The requirements of this annex are intended to control the quality of the radioscopy examination and not to specify the accept/reject criteria for the test object. Accept/reject criteria are provided in other contract documents.

A2.2 Terminology

A2.2.1 component — the test part or parts described, assembled, or processed to the extent specified by the drawing.

A2.2.2 contract documents — the procuring contract and all drawings, specifications, standards, and other information included with or referred to by the procuring contract.

A2.2.3 contractor — a contractor having first level responsibility for the design, manufacture, and delivery of an end item. When radioscopy examination is required, the contractor is the user of radioscopy examination services.

A2.2.4 mandatory radioscopy examination — those radioscopy examinations which are a part of the required radiographic examinations specified in the contract documents.

A2.2.5 NDE facility — the organization that is responsible for providing nondestructive examination services.

A2.2.6 optional radioscopy examination — those radioscopy examinations that are conducted for process verification or information only and are not a part of

the required radiographic examinations specified in the contract documents.

A2.2.7 provider of radioscopy services — a contractor, subcontractor, or other entity that provides radioscopy examination services.

A2.2.8 test object — the material, component, or assembly that is the subject of the radioscopy examination.

A2.2.9 user of radioscopy services — a contractor, subcontractor, or other entity that procures radioscopy examination services. The provider and user of radioscopy examination services may be a part of the same organization or different organizations.

A2.2.10 written procedure — in radioscopy, a series of steps that are to be followed in a regular definite order. The radioscopy system operator follows the written procedure to consistently obtain the desired results and image quality level when performing radioscopy examination. The development of a radioscopy technique usually precedes the preparation of a written procedure.

A2.2.11 Other definitions not given herein shall be as specified in Terminology E 1316.

A2.3 General Requirements

A2.3.1 Equipment Qualification — Radioscopy system qualification shall be in accordance with Practice E 1411, using Practice E 747 and Practice E 1025 image quality indicators or a calibration block containing actual or simulated defects.

A2.3.2 Personnel Qualification — Radioscopy personnel shall be qualified and certified in accordance with the requirements of SNT-TC-1A or ANSI/ASNT CP-189. Radioscopy system qualification, the development of radioscopy examination test techniques, scan plans, and the overall implementation of radioscopy examination in accordance with this annex shall be under the control and supervision of a qualified Level III with additional radioscopy training and experience, or in conjunction with an individual having the necessary training and experience in radioscopy examination. Operation of the radioscopy system, including interpretation of the radioscopy image, shall be made by qualified Level II personnel.

A2.3.3 Safety — The performance of radioscopy examination shall present no hazards to the safety of personnel or property. Applicable Federal, state, and local radiation safety codes shall be adhered to. All radioscopy procedures shall be performed so that per-

sonnel shall receive the minimum dosage and in no case exceed Federal, state, and local limits.

A2.3.4 Archival Recording of Mandatory Radioscopic Examinations — The radioscopy examination record shall contain the results for mandatory radioscopy examinations. The radioscopy examination record shall be suitably archived for a period of one year after the date of radioscopy examination or for a longer time if specified in the contract documents. Efficient radioscopy examination record recall shall be available at any time over the record retention period. The radioscopy examination record shall be traceable to the test object by serial number or other means. This requirement will not apply to optional radioscopy examinations that are not specified in the contract documents.

A2.3.4.1 Radioscopic Examination Record — The recorded radioscopy examination record for mandatory examinations shall include the written results of the radioscopy examination and the radioscopy image, if an image is utilized in the accept/reject decision-making process. The recorded radioscopy image shall be provided with such additional information as may be required to allow the subsequent off-line review of the radioscopy examination results and, if necessary, the repeating of the radioscopy examination.

A2.3.4.2 Image Recording Media — The radioscopy image shall be recorded on a media that is appropriate to the radioscopy examination requirement. The recorded image shall reference the examination zones in such a way that the reviewer can confirm that all zones have been covered. The recorded radioscopy image shall provide an image quality at least equal to that for which the radioscopy system is qualified. The recording media shall be capable of maintaining the required image quality for the required record storage period or not less than five years from the recording date. The recorded radioscopy image playback shall be maintained in an operable condition for the duration of the record storage period measured from the date when the last radioscopy image was recorded.

A2.3.4.3 Recording Media Storage Conditions — Media storage and handling shall be in accordance with Guide E 1453.

A2.3.4.4 Other Recording — Where the recording of the radioscopy examination record is not in fulfillment of mandatory archival recording requirements, other recording methods and media may be used.

A2.3.5 Image Quality Indicators — An IQI must be chosen with care to demonstrate the radioscopy system's ability to detect discontinuities, or other features of interest. Practice E 1025 plaque-type and Practice E 747 wire-type IQIs and calibration blocks with real or simulated defects that match the application are all acceptable unless a specific IQI is specified in the contract documents. The selected IQI or calibration block shall be detailed in the written procedure. An IQI or calibration block may not be required for the following radioscopy examinations:

A2.3.5.1 Examining assemblies for debris or foreign objects.

A2.3.5.2 Conducting radioscopy for adequate defect removal or grind-out. However, the final acceptance radioscopy examination shall include an IQI.

A2.3.5.3 Examinations to show material details or contrast between two or more dissimilar materials in component parts or assemblies including honeycomb areas for the detection of fabrication irregularities or the presence or absence of material.

A2.3.5.4 Examining electronic components for contamination, loose or missing elements, solder balls, broken or misplaced wires, or connectors and potted assemblies for broken internal components or missing potting compound.

A2.3.5.5 Optional radioscopy examinations.

A2.3.5.6 Where the use of an IQI is impractical or ineffective, an alternate method may be used, subject to the approval of the contracting agency.

A2.3.6 Classification of Test Object Zones for Radioscopy — The classification of test objects into zones for various accept/reject criteria shall be determined from the contract documents. In cases where no accept/reject criteria are specified, the Level III of the NDE facility shall document those anomalies considered critical and indicate in writing that no formal accept/reject criteria were provided.

A2.4 Detailed Requirements

A2.4.1 Application Qualification — Radioscopy may be used where appropriate for new as well as existing radiographic examination requirements provided that the required performance, including image quality, can be met. Where radioscopy is used to replace or augment existing radiographic applications, the radioscopy results should correlate favorably with the results obtained with radiographic film-produced techniques.

Favorable correlation means that the radioscopic and film images show similar sensitivity to test object features which are of interest.

A2.4.2 Written Procedure — It shall be the responsibility of the NDE facility to develop a written radioscopic examination procedure to ensure the effective and repeatable radioscopic examination of the test object. When a dynamic radioscopic system is used, a test object scan plan meeting the requirements of Practice E 1255 (see 5.2.1.2) shall be included in the written procedure. Those portions of the contract document that specify and detail radioscopic examination shall become an appendix to the written procedure. The written procedure must be written or approved by the Level III of the NDE facility. Where required, the written procedure shall be approved by the contracting agency prior to use. The written procedure shall include as a minimum the following information:

A2.4.2.1 A drawing, sketch, or photograph of the component that shows the radiation beam axis, position(s) of the detector and applicable IQI for each and all variations of the test object orientation, and beam energy. This requirement may be expressed in coordinates for automated systems having calibrated manipulation systems.

A2.4.2.2 A physical description of the test object including size, weight, and composition.

A2.4.2.3 Classification of test object into zones for radioscopy.

A2.4.2.4 Test part masking, if used, for each required view.

A2.4.2.5 Added radiation source collimation, expressed in terms of the radiation field dimensions at the test object source side for each required view.

A2.4.2.6 Detector field of view for each required view.

A2.4.2.7 Detector diaphragm settings, expressed in terms of field of view at the detector for each required view.

A2.4.2.8 The allowable range of radiation energy and beam current or source intensity and the focal spot or source size for each required view.

A2.4.2.9 Added beam filtration, if used, for each required view.

A2.4.2.10 The inspection geometry and coverage for each required view.

A2.4.2.11 Type of IQI or calibration block used and the required quality level.

A2.4.2.12 All hardware and software settings which can be changed by the operator to affect the outcome of the radioscopic examination. Such settings include, but are not limited to, video camera, display settings, and image processor variables.

A2.4.2.13 The recording media and stored image format for mandatory radioscopic image storage.

A2.4.3 Test Object Examination — The number of test objects to be examined and the coverage required for each test object shall be specified in the contract documents. If not specified, all test objects shall receive 100% radioscopic coverage as detailed in the written procedure.

A2.4.4 Image Quality — Unless otherwise specified in the contract documents, the required image quality level is 2-2T. Image quality assessment shall be made in the same mode as that used for the inspection.

A2.4.4.1 The IQI may be placed on the test object or on a mounting block at or near the test object location. In the case of small radioscopic fields of view or other situations where it is not practical to place the IQI in the field of view with the test object and maintain it normal to the X-ray beam, the IQI may be imaged immediately before and after the test object examination or batch of test objects if they are similar. The radioscopic examination results shall be invalid if the before and after IQI images fail to demonstrate the required sensitivity. Before and after IQI images shall be considered a part of the test object image for radioscopic image interpretation and archiving purposes.

A2.4.5 Radioscopic System Qualification — The radioscopic system including mandatory radioscopic image archiving devices shall be qualified to the image quality level required for test object examination. Radioscopic system initial qualification and periodic requalification shall be in accordance with Practice E 1411.

A2.4.6 Radioscopic System Requalification — The radioscopic system, including mandatory image archiving devices, shall be periodically requalified at intervals frequent enough to ensure the required level of radioscopic system performance.

A2.4.7 Inspection Image Control — The radioscopic system shall be checked for performance before each day's production usage using the method and devices that were initially used to qualify the written procedure. A log shall be maintained to document any

changes in system performance requiring changes in operating parameters and listing all equipment maintenance. System requalification shall be required whenever image quality requirements can no longer be met.

A2.4.8 Repair of Radioscopic System — Repair or replacement of key radioscopic system components including but not limited to the radiation source, image forming, image transmission, image processing, and image display subsystems shall be cause for system requalification. In no case shall the interval between qualification tests exceed one year. The qualification statement shall be posted on the radioscopic system. The results of the qualification tests shall be maintained in the radioscopic system equipment file at least until completion of the next qualification procedure or the expiration of the archival image retention period, whichever is longer.

A2.4.9 Image Interpretation:

A2.4.9.1 Static Imaging — Radioscopic system qualification in accordance with Practice E 1411 applies to static imaging conditions, only where the test part is stationary with respect to the X-ray beam. Therefore, all performance measurements are based upon static image quality. All mandatory radioscopic examination accept/reject decisions shall be based upon the assessment of static images.

A2.4.9.2 Dynamic Imaging — Dynamic or in-motion imaging may be used to gain useful information about the test object. However, the final assessment of image information for mandatory radioscopic examinations shall be made in the static mode.

A2.4.10 Feature Size Determination — Where feature measurement from the radioscopic image is required, the written procedure shall include methodology for determining and maintaining the accuracy of the selected measurement method.

A2.4.10.1 Feature Measurement by Test Object Displacement — For those radioscopic systems with calibrated manipulation systems, the more accurate and therefore preferred method of measurement is to manipulate the extremities of the feature to be measured to a common central reference point within the radioscopic image field of view. The dimension may then be read from the manipulation system position display.

A2.4.10.2 Feature Measurement by Comparison — A second method involves comparing the test object feature with a known, observable dimension which must be wholly within the radioscopic field of view. Many digital image processors facilitate this type

of measurement by counting pixels over the feature length. The pixel number is often converted to engineering units by comparison with a known length. However, the orientation and position along the X-ray beam (magnification) of both the feature and the calibrating reference length affect the accuracy of such measurements.

A2.4.11 Gray Scale Range — The gray scale range required to meet initial qualification contrast sensitivity requirements for image quality shall be recorded and monitored. For systems using human image assessment, it is particularly important that the gray scale range and the number of gray scale steps be closely matched to the response of the human eye. The written procedure shall include a means for monitoring the required gray scale range using a contrast sensitivity gage, step wedge, or similar device made of the test object or IQI material.

A2.4.12 Timing of Radioscopic Examination — Radioscopic examination shall be performed at the time of manufacturing, assembly, or rework as required by the contract documents.

A2.4.13 Identification — A means shall be provided for the positive identification of the test object to the archival radioscopic inspection record. Archived radioscopic images shall be annotated to agree with the test object identification.

A2.4.14 Locating the Radioscopic Examination Areas — Whenever more than one image is required for a weldment or other test object, location markers shall be placed on the test object in order that the orientation of the test object and the location of test object features relative to the radioscopic field of view may be established. This requirement shall not apply to automated systems having programmed radioscopic examination sequences where coverage has been proven during the development of the scan plan. Also, this requirement does not apply to the radioscopic examination of simple or small shapes where the test part orientation is obvious and coverage is not in question.

A2.4.15 Surface Preparation — Test objects may be inspected without surface preparation except as may be required to remove surface conditions which may interfere with proper interpretation of the radioscopic image or create a safety hazard.

A2.4.16 Detailed Data — The provider of radioscopic examination services shall keep the written procedure, qualification documentation, and the signed inspection reports or tabulated results for five years from the

radioscopic examination date unless otherwise specified in the contract documents. For software-based automated radioscopic systems using custom software, a copy of the source code and the related inspection parameters shall also be maintained on file for a like period of time. This requirement shall not apply to standard commercially available software packages where a separate copy of the software is maintained.

A2.4.17 Radioscopic Reexamination of Repairs — When repair has been performed as the result of radioscopic examination, the repaired areas shall be reexamined using the same radioscopic technique to evaluate the effectiveness of the repair. Each repaired area shall be identified with R1, R2, R3, and so forth, to indicate the number of times repair was performed.

A2.4.18 Retention of Radioscopic Examination Record — Mandatory radioscopic examination records and associated radioscopic images shall be stored in a proper repository at the contractor's plant for one year from the date from which they were made. Special instructions, such as storage for other periods of time, making backup copies, copying the records to other media, or having the records destroyed shall be specified in the contract documents.

A2.4.19 Rejection of Test Objects — Test objects containing defects exceeding the permissible limits specified in the contract documents shall be separated from acceptable material, appropriately identified as discrepant, and submitted for material review when required by the contract documents.

A2.4.20 Reexamination — Where there is an inability to interpret the radioscopic results because of improper execution or equipment malfunction, the test object shall be reexamined using the correct procedure. If the problem is not resolved by reexamination, the procedure shall be reviewed by the Level III of the NDE facility and adjusted, if necessary. Reference exposures may be made using radiography if necessary. If the reexamination was caused by equipment malfunction, the equipment may not be returned to service until the malfunction is repaired and the equipment is requalified to the current qualification requirements in accordance with Practice E 1411.

A2.4.21 Test Object Disposition — Test objects that have undergone radioscopic examination shall be marked or physically separated in such a manner so as to minimize the possibility of rejected or questionable test objects being confused with acceptable ones.

A2.5 Notes

A2.5.1 This section contains information of a general or explanatory nature and is not mandatory.

A2.5.1.1 Caution — Active electronic components and some materials, such as tetrafluoroethylene, are subject to radiation damage if exposed to large doses of radiation. While normal radioscopic examinations should cause no problem, extended periods of radiation exposure should be avoided.

A2.5.1.2 Human Factors — The success of radioscopic examinations which involve human image interpretation are, like radiography, subject to human factors. Careful attention should be given to the human environment where image interpretation takes place, to make it as conducive to correct, consistent image interpretation as possible. Measures should also be implemented to ensure that fatigue does not interfere with correct and consistent radioscopic image interpretation.

A2.5.1.3 Use of IQI — As with radiography, the achievement of the required IQI sensitivity does not guarantee the ability to find all defects down to the minimum defect size. This is due to the fact that many defects, especially those of a planar nature, are very orientation sensitive. When a dynamic radioscopic system is used, care must be taken to see that the scan plan includes sufficient manipulation to maximize the possibility that orientation-sensitive defects will be found. It is for this reason that the use of calibration blocks with real or simulated defects may more accurately characterize the ability of the radioscopic system to find orientation-sensitive defects.

A2.5.1.4 Use of Image-Processing Techniques — Care should be exercised in applying digital image-processing techniques to evaluate the overall effect upon image quality. For example, contrast enhancement techniques may emphasize contrast in one brightness range while decreasing contrast in other brightness ranges. Some spatial filters have directional aspects whereby features in one direction are emphasized while those in the orthogonal direction are deemphasized. Such cautions are intended to cause the careful evaluation of digital image-processing techniques and not to discourage their use.

A2.5.1.5 Feature Size Determination — As with radiography, great care must be exercised in trying to assess test part feature dimensions from a two-dimensional projected view.

STANDARD TEST METHOD FOR RADIOSCOPIC EXAMINATION OF WELDMENTS



SE-1416



(Identical with ASTM Specification E 1416-96)

1. Scope

1.1 This test method covers a uniform procedure for radiosopic examination of weldments. Requirements expressed in this test method are intended to control the quality of the radiosopic images and are not intended for controlling acceptability or quality of welds.

1.2 This test method applies only to the use of equipment for radiosopic examination in which the image is finally presented on a television monitor for operator evaluation. The examination may be recorded for later review. It does not apply to fully automated systems where evaluation is automatically performed by computer.

1.3 The radiosopic extent, the quality level, and the acceptance criteria to be applied shall be specified in the contract, purchase order, product specification, or drawings.

1.4 This test method can be used for the detection of discontinuities. This test method also facilitates the examination of a weld from several directions, such as perpendicular to the weld surface and along both weld bevel angles. The radiosopic techniques described in this test method provide adequate assurance for defect detectability; however, it is recognized that, for special applications, specific techniques using more stringent requirements may be needed to provide additional detection capability. The use of specific radiosopic techniques shall be agreed upon between purchaser and supplier.

1.5 The values stated in inch-pound units are to be regarded as the standard. The SI units given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use.*

It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Specific precautionary statements are given in Section 7.

2. Referenced Documents

2.1 ASTM Standards:

- E 94 Guide for Radiographic Testing
- E 543 Practice for Agencies Performing Nondestructive Testing
- E 747 Practice for Design, Manufacture, and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology
- E 1000 Guide for Radioscopy
- E 1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology
- E 1255 Practice for Radioscopy
- E 1316 Terminology for Nondestructive Examinations

2.2 ASNT Standards:

- ASNT Recommended Practice No. SNT-TC-1A Personnel Qualification and Certification in Nondestructive Testing
- ANSI/ASNT CP-189-ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 Military Standard:

- MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification (Eddy Current, Liquid Penetrant, Magnetic Particle, Radiographic, Ultrasonic)

3. Terminology

3.1 Definitions:

3.1.1 Definitions of terms applicable to this test method may be found in Terminology E 1316.

4. Materials

4.1 Recording Media — Recording media for storage of images shall be in a format agreed by the purchaser and supplier. This may include either analog or digital media.

5. Apparatus

5.1 Radiation Source (X-Ray or Gamma-Ray) — Selection of the appropriate source is dependent upon variables regarding the weld being examined, such as material composition and thickness. The suitability of the source shall be demonstrated by attainment of the required image quality and compliance with all other requirements stipulated herein. Guidance on the selection of the radiation source may be found in Guide E 1000 and Practice E 1255.

5.2 Manipulation System — Selection of the appropriate manipulation system (where applicable) is dependent upon variables such as the size and orientation of the object being examined and the range of motions, speed of manipulation, and smoothness of motion. The suitability of the manipulation system shall be demonstrated by attainment of the required image quality and compliance with all other requirements stipulated herein. Guidance on the selection of the manipulation system may be found in Practice E 1255.

5.3 Imaging System — Selection of the appropriate imaging system is dependent upon variables such as the size of the object being examined and the energy and intensity of the radiation used for the examination. The suitability of the imaging system shall be demonstrated by attainment of the required image quality and compliance with all other requirements stipulated herein. Guidance on the selection of an imaging system may be found in Guide E 1000 and Practice E 1255.

5.4 Image Processing System — Where agreed between purchaser and supplier, image processing systems may be used for noise reduction through image integration or averaging, contrast enhancement and other image processing operations.

5.5 Collimation — Selection of appropriate collimation is dependent upon the geometry of the object being

examined. It is generally useful to select collimation to limit the primary radiation beam to the weld and the immediately adjacent base material in order to improve radioscopic image quality.

5.6 Filters and Masking — Filters and masking may be used to improve image quality from contrast reductions caused by low-energy scattered radiation. Guidance on the use of filters and masking can be found in Guide E 94.

5.7 Image Quality Indicators (IQI) — Unless otherwise specified by the applicable job order or contract, image quality indicators shall comply with the design and identification requirements specified in Practices E 747 or E 1025.

5.8 Shims, Separate Blocks, or Like Sections — Shims, separate blocks, or like sections made of the same or radioscopically similar materials (as defined in Practice E 1025) may be used to facilitate image quality indicator positioning as described in 9.10.3. The like section should be geometrically similar to the object being examined.

5.9 Location and Identification Markers — Lead numbers and letters should be used to designate the part number and location number. The size and thickness of the markers shall depend on the ability of the radioscopic technique to discern the markers on the images. As a general rule, markers from 0.06 to 0.12 in. (1.5 to 3 mm) thick will suffice for most low energy (less than 1 MeV) X-ray and iridium-192 radioscopy. For higher energy (greater than 1 MeV and cobalt-60) radioscopy, it may be necessary to use markers that are thicker [0.12 in. (3 mm) thick or more]. In cases where the system being used provides a display of object position within the image, this shall be acceptable as identification of object location.

6. Basis of Application

6.1 Personnel Qualification — NDT personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, MIL STD 410, or a similar document. The practice or standard used and its applicable revision shall be specified in the contractual agreement between the using parties.

6.2 Qualification of Nondestructive Testing Agencies — If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E 543. The applicable edition of Practice E 543 shall be specified in the contractual agreement.

6.3 Time of Examination — The time of examination shall be in accordance with 9.1 unless otherwise specified.

6.4 Procedures and Techniques — The procedures and techniques to be utilized shall be as described in this test method unless otherwise specified. Specific techniques may be specified in the contractual agreement.

6.5 Extent of Examination — The extent of examination shall be in accordance with 8.3 unless otherwise specified.

6.6 Reporting Criteria/Acceptance Criteria — Reporting criteria for the examination results shall be in accordance with Section 10 unless otherwise specified. Acceptance criteria shall be specified in the contractual agreement.

6.7 Reexamination of Repaired/Reworked Items — Reexamination of repaired/reworked items is not addressed in this test method and if required shall be specified in the contractual agreement.

7. Safety

7.1 Radioscopic procedures shall comply with applicable city, state, and federal safety regulations.

8. Requirements

8.1 Procedure Requirement — Unless otherwise specified by the applicable job order or contract, radioscopic examination shall be performed in accordance with a written procedure. Specific requirements regarding the preparation and approval of the written procedures shall be as agreed by purchaser and supplier. The production procedure shall address all applicable portions of this test method and shall be available for review during interpretation of the images. The written procedure shall include the following:

8.1.1 Material and thickness range to be examined,

8.1.2 Equipment to be used, including specifications of source parameters (such as tube voltage, current, focal spot size) and imaging equipment parameters (such as detector size, field of view, electronic magnification, camera black level, gain),

8.1.3 Examination geometry, including source-to-object distance, object-to-detector distance and orientation,

8.1.4 Image quality indicator designation and placement,

8.1.5 Test-object scan plan, indicating the range of motions and manipulation speeds through which the test object shall be manipulated in order to ensure satisfactory results (see description in 5.2.1.2 of Practice E 1255),

8.1.6 Image-processing parameters,

8.1.7 Image-display parameters, and

8.1.8 Image storage.

8.2 Radioscopic Coverage — Unless otherwise specified by purchaser and supplier agreement, the extent of radioscopic coverage shall include 100% of the volume of the weld and the adjacent base metal.

8.3 Examination Speed — For dynamic examination, the speed of object motion relative to the radiation source and detector shall be controlled to ensure that the required radioscopic quality level is achieved.

8.4 Radioscopic Image Quality — All images shall be free of marks or other blemishes that could mask or be confused with the image of any discontinuity in the area of interest. It may be possible to prevent blemishes from masking discontinuities or being confused with discontinuities by moving the object being examined relative to the imaging device. If any doubt exists as to the true nature of an indication exhibited in the image, the image shall be rejected and a new image of the area shall be made.

8.5 Radioscopic Quality Level — Radioscopic quality level shall be determined upon agreement between the purchaser and supplier and shall be specified in the applicable job order or contract. Radioscopic quality shall be specified in terms of equivalent penetrameter (IQI) sensitivity and shall be measured using image quality indicators conforming to Practices E 747 or E 1025.

8.6 Acceptance Level — Accept and reject levels shall be stipulated by the applicable contract, job order, drawing, or other purchaser and supplier agreement.

8.7 Image-Viewing Facilities — Viewing facilities shall provide subdued background lighting of an intensity that will not cause troublesome reflection, shadows, or glare on the image.

8.8 Storage of Images — When storage is required by the applicable job order or contract, the images should be stored in a format stipulated by the applicable contract, job order, drawing, or other purchaser and

supplier agreement. The image-storage duration and location shall be as agreed between purchaser and supplier.

9. Procedure

9.1 Time of Examination — Unless otherwise specified by the applicable job order or contract, perform radiography prior to heat treatment.

9.2 Surface Preparation — Unless otherwise agreed upon, remove the weld bead ripple or weld-surface irregularities on both the inside and outside (where accessible) by any suitable process so that the image of the irregularities cannot mask, or be confused with, the image of any discontinuity. Interpretation can be optimized if surface irregularities are removed such that the image of the irregularities is not discernible.

9.3 Source to Detector Distance — Unless otherwise specified in the applicable job order or contract, geometric unsharpness (U_g) shall not exceed the following:

Material Thickness	U_g , max, in. (mm)
under 2 in. (50 mm)	0.020 (0.50)
2 through 3 in. (50 through 75 mm)	0.030 (0.75)
over 3 through 4 in. (75 through 100 mm)	0.040 (1.00)
greater than 4 in. (100 mm)	0.070 (1.75)

Determine geometric unsharpness values as specified in Guide E 94.

9.4 Examination Speed — For dynamic examination, determine the speed of object motion relative to the radiation source and detector upon agreement between the purchaser and supplier. Base this determination upon the achievement of the required radioscopic quality level at that examination speed.

9.5 Direction of the Radiation — Direct the central beam of radiation perpendicularly toward the center of the effective area of the detector or to a plane tangent to the center of the image, to the maximum extent possible, except for double-wall exposure-double-wall viewing elliptical projection techniques, as described in 9.14.2.

9.6 Scattered Radiation — Scattered radiation (radiation scattered from the test object and from surrounding structures) reduces radioscopic contrast and may produce undesirable effects on radioscopic quality. Use precautions such as collimation of the source, collimation of the detector, and additional shielding as appropriate to minimize the detrimental effects of this scattered radiation.

9.7 Image Quality Indicator Selection — For selection of the image quality indicator, the thickness on which the image quality indicator is based is the single-wall thickness plus the lesser of the actual or allowable reinforcement. Backing strips or rings are not considered as part of the weld or reinforcement thickness for image quality indicator selection. For any thickness, an image quality indicator acceptable for thinner materials may be used, provided all other requirements for radiography are met.

9.8 Number of Image Quality Indicators:

9.8.1 Place at least one image quality indicator (Practices E 747 or E 1025) in the area of interest representing an area in which the brightness is relatively uniform. The degree of brightness uniformity shall be agreed upon between purchaser and supplier. If the image brightness in an area of interest differs by more than the agreed amount, use two image quality indicators. Use one image quality indicator to demonstrate acceptable image quality in the darkest portion of the image and use one image quality indicator to demonstrate acceptable image quality in the lightest portion of the image.

9.8.2 When a series of images are made under identical conditions, it is permissible for the image quality indicators to be used only on the first and last images in the series, provided this is agreed upon between the purchaser and supplier. In this case, it is not necessary for the image quality indicators to appear in each image.

9.8.3 Always retain qualifying images, on which one or more image quality indicators were imaged during exposure, as part of the record to validate the required image quality indicator sensitivity and placement.

9.9 Image Quality Indicator Placement:

9.9.1 Place the image quality indicator on the source side adjacent to the weld being examined. Where the weld metal is not radioscopically similar to the base material or where geometry precludes placement adjacent to the weld, place the image quality indicator over the weld or on a separate block, as described in 9.10.

9.9.2 Detector-Side Image Quality Indicators — In those cases where the physical placement of the image quality indicators on the source side is not possible, place the image quality indicators on the detector side. The applicable job order or contract shall specify the applicable detector-side quality level. The

accompanying documents shall clearly indicate that the image quality indicators were located on the detector side.

9.10 *Separate Block* — When configuration or size prevents placing the image quality indicators on the object being examined, use a shim, separate block or like section conforming to the requirements of 5.8 provided the following conditions are met:

9.10.1 The image quality indicator is no closer to the detector than the source side of the object being examined (unless otherwise specified).

9.10.2 The radioscopic brightness in the area of the image quality indicator including the shim, separate block, or like section and IQI where applicable are similar to the brightness in the area of interest.

9.10.3 The shim, separate block, or like section is placed as close as possible to the object being examined.

9.10.4 When hole-type image quality indicators are used, the shim, separate block, or like section dimensions shall exceed the image quality indicator dimensions such that the outline of at least three sides of the image quality indicator image is visible on the image.

9.11 *Shim Utilization* — When a weld reinforcement or backing ring and strip is not removed, place a shim of material that is radioscopically similar to the backing ring and strip under the image quality indicators to provide approximately the same thickness of material under the image quality indicator as the average thickness of the weld reinforcement plus the wall thickness, backing ring and strip.

9.11.1 *Shim Dimensions and Location* — When hole-type image quality indicators are used, the shim dimensions and location shall exceed the image quality indicator dimensions by at least 0.12 in. (3 mm) on at least three sides. At least three sides of the image quality indicator shall be discernible in accordance with 9.10.4 except that only the two ends of the image quality indicator need to be discernible when located on piping less than 1 in. (25 mm) nominal pipe size. Place the shim so as not to overlap the weld image including the backing strip or ring.

9.11.2 *Shim Image Brightness* — The image brightness of the shim image shall be similar to the image brightness of the area of interest.

9.12 *Location Markers* — Place location markers outside the weld area. The radioscopic image of the

location markers for the identification of the part location with the image shall appear on the image without interfering with the interpretation and with such an arrangement that it is evident that complete coverage was obtained.

9.12.1 *Double-Wall Technique* — When using a technique in which radiation passes through two walls and the welds in both walls are simultaneously viewed for acceptance, and the entire image of the object being examined is displayed, only one location marker is required in the image.

9.12.2 *Series of Images* — For welds that require a series of images to cover the full length or circumference of the weld, apply the complete set of location markers at one time, wherever possible. A reference or zero position for each series must be identified on the component. A known feature on the object (for example, keyway, nozzle, and axis line) may also be used for establishment of a reference position. Indicate this feature on the radioscopic record.

9.12.3 *Similar Welds* — On similar type welds on a single component, the sequence and spacing of the location markers must conform to a uniform system that shall be positively identified in the radioscopic procedure or interpretation records. In addition, reference points on the component will be shown on the sketch to indicate the direction of the numbering system.

9.13 *Image Identification* — Provide a system of positive identification of the image. As a minimum, the following shall appear on the image: the name or symbol of the company performing radioscopy, the date, and the weld identification number traceable to part and contract. Identify subsequent images made of a repaired area with the letter "R."

9.14 *Radioscopic Techniques:*

9.14.1 *Single-Wall Technique* — Except as provided in 9.14.2, 9.14.3, and 9.14.4, perform radioscopy using a technique in which the radiation passes through only one wall.

9.14.2 *Double-Wall Technique for Circumferential Welds* — For circumferential welds 4 in. (100 mm) outside diameter (3.5 in. nominal pipe size) or less, use a technique in which the radiation passes through both walls and both walls are viewed for acceptance on the same image. Unless otherwise specified, either elliptical or superimposed projections may be used. A sufficient number of views should be taken to examine the entire weld. Where design or access restricts a practical technique from examining the entire weld,

agreement between contracting parties must specify necessary weld coverage.

9.14.3 For circumferential welds greater than 4 in. (100 mm) outside diameter (3.5 in. nominal pipe size), use a technique in which only single-wall viewing is performed. A sufficient number of views should be taken to examine the entire weld. Where design or access restricts a practical technique from examining the entire weld, agreement between contracting parties must specify necessary weld coverage.

9.14.4 For radioscopic techniques that prevent single-wall exposures due to restricted access, such as jacketed pipe or ship hull, the technique should be agreed upon in advance between the purchaser and supplier. It should be recognized that image quality indicator sensitivities based on single-wall thickness may not be obtainable under some conditions.

10. Records

10.1 Maintain the following radioscopic records as agreed between purchaser and supplier:

10.1.1 Radioscopic standard shooting sketch, including examination geometry, source-to-object distance, object-to-detector distance and orientation,

10.1.2 Material and thickness range examined,

10.1.3 Equipment used, including specification of source parameters (such as tube voltage, current, focal spot size) and imaging equipment parameters (such as detector size, field of view, electronic magnification, camera blacklevel, gain, etc.) and display parameters,

10.1.4 Image quality indicator (and shim, if used) placement,

10.1.5 Test-object scan plan, including ranges of motion and manipulation speeds,

10.1.6 Image processing parameters,

10.1.7 Image-storage data,

10.1.8 Weld repair documentation, and

10.1.9 *Image* — Interpretation record shall contain as a minimum the following information:

10.1.9.1 Disposition of each image (acceptable or rejectable),

10.1.9.2 If rejectable, cause for rejection (slag, crack, porosity, etc.),

10.1.9.3 Surface indication verified by visual examination (grinding marks, weld ripple, spatter, etc.), and

10.1.9.4 Signature of the image interpreter, including level.

11. Precision and Bias

11.1 No statement is made about either precision or bias of this test method since the result merely states whether there is conformance to the criteria of success specified in the procedure.

12. Keywords

12.1 gamma ray; nondestructive testing; radioscopic examination; radioscopy; weldments; x-ray

STANDARD PRACTICE FOR DETERMINING CONTRAST SENSITIVITY IN RADIOSCOPY

01



SE-1647



(Identical with ASTM Specification E 1647-98a)

1. Scope

1.1 This practice covers the design and material selection of a contrast sensitivity measuring gage used to determine the minimum material thickness or density that may be imaged without regard to spatial resolution limitations.

1.2 This practice is applicable to transmitted-beam radioscopic imaging systems utilizing X-ray and gamma ray radiation sources.

1.3 The values stated in inch-pound units are to be regarded as standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific safety statements, see NIST/ANSI Handbook 114 Section 8, Code of Federal Regulations 21 CFR 1020.40 and 29 CFR 1910.96.

2. Referenced Documents

2.1 ASTM Standards:

- B 139 Specification for Phosphor Bronze Rod, Bar, and Shapes
- B 150 Specification for Aluminum Bronze Rod, Bar, and Shapes
- B 161 Specification for Nickel Seamless Pipe and Tube
- B 164 Specification for Nickel-Copper Alloy Rod, Bar, and Wire
- B 166 Specification for Nickel-Chromium-Iron Alloys (UNS N06600, N06601, and N06690) and Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617) Rod, Bar, and Wire

- E 747 Practice for the Design Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used For Radiology
- E 1316 Terminology for Nondestructive Examination
- E 1025 Practice for Hole-Type Image Quality Indicators Used for Radiography
- E 1411 Practice for Qualification of Radioscopic Systems

2.2 Federal Standards:

- 21 CFR 1020.40 Safety Requirements for Cabinet X-ray Systems
- 29 CFR 1910.96 Ionizing Radiation

2.3 NIST/ANSI Standards:

- NIST/ANSI Handbook 114 General Safety Standard for Installations Using Non-Medical X-ray and Sealed Gamma Ray Sources, Energies to 10 MeV

2.4 Other Standard:

- EN 462-5 Duplex Wire Image Quality Indicator

3. Terminology

3.1 Definitions — Definitions of terms applicable to this test method may be found in Terminology E 1316.

4. Summary of Practice

4.1 It is often useful to evaluate the contrast sensitivity of a penetrating radiation imaging system separate and apart from spatial resolution measurements. Conventional image quality indicators (IQIs), such as Test Method E 747 wire and Practice E 1025 plaque IQIs, combine the contrast sensitivity and resolution measurements into an overall performance figure of merit. Such figures of merit are often not adequate to detect subtle changes in imaging system performance. For example, in a high contrast image, spatial resolution can degrade

with almost no noticeable effect upon overall image quality. Similarly, in an application in which the imaging system provides a very sharp image, contrast can fade with little noticeable effect upon the overall image quality. These situations often develop and may go unnoticed until the system performance deteriorates below acceptable image quality limits.

5. Significance and Use

5.1 The contrast sensitivity gage measures contrast sensitivity independent of the imaging system spatial resolution limitations. The thickness recess dimensions of the contrast sensitivity gage are large with respect to the spatial resolution limitations of most imaging systems. Four levels of contrast sensitivity are measured: 4%, 3%, 2%, and 1%.

5.2 The contrast sensitivity gage is intended for use in conjunction with a high-contrast resolution measuring gage, such as the EN 462-5 Duplex Wire Image Quality Indicator. Such gages measure spatial resolution essentially independent of the imaging system's contrast sensitivity. Such measurements are appropriate for the qualification and performance monitoring of radiographic and radiosopic imaging systems.

5.3 Radioscopic system performance may be specified by combining the measured contrast sensitivity expressed as a percentage with the spatial resolution expressed in millimeters of unsharpness. For the EN 462-5 spatial resolution gage, the unsharpness is equal to twice the wire diameter. For the line pair gage, the unsharpness is equal to the reciprocal of the line-pair/mm value. As an example, an imaging system that exhibits 2% contrast sensitivity and images the 0.1 mm EN 462-5 paired wires (equivalent to imaging 5 line-pairs/millimeter resolution on a line-pair gage) performs at a 2%–0.2 mm sensitivity level. A standard method of evaluating overall radioscopic system performance is given in Practice E 1411.

6. Contrast Sensitivity Gage Construction and Material Selection

6.1 Contrast sensitivity gages shall be fabricated in accordance with Fig. 1, using the dimensions given in Tables 1, 2, and 3.

6.2 The gage shall preferably be fabricated from the test object material. Otherwise, the following material selection guidelines are to be used:

6.2.1 Materials are designated in eight groupings, in accordance with their penetrating radiation absorption

TABLE 1
DESIGN OF THE CONTRAST SENSITIVITY GAGE

Gage Thickness	J Recess	K Recess	L Recess	M Recess
T	1% of T	2% of T	3% of T	4% of T

TABLE 2
CONTRAST SENSITIVITY GAGE DIMENSIONS

Gage Size	B DIM.	C DIM.	D DIM.	E DIM.	F,G DIM.
1	0.750 in. 19.05 mm	3.000 in. 76.20 mm	0.250 in. 6.35 mm	0.625 in. 15.88 mm	0.250 in. 6.35 mm
2	1.500 in. 38.10 mm	6.000 in. 152.40 mm	0.500 in. 12.70 mm	1.250 in. 31.75 mm	0.500 in. 12.7 mm
3	2.250 in. 57.15 mm	9.000 in. 228.60 mm	0.750 in. 19.05 mm	1.875 in. 47.63 mm	0.750 in. 19.05 mm
4	3.000 in. 76.20 mm	12.000 in. 304.80 mm	1.000 in. 25.40 mm	2.500 in. 63.50 mm	1.000 in. 25.4 mm

TABLE 3
CONTRAST SENSITIVITY GAGE APPLICATION

Gage Size	Use on Thicknesses
1	Up to 1.5 in. (38.1 mm)
2	Over 1.5 in. (38.1 mm) to 3.0 in. (76.2 mm)
3	Over 3.0 in. (76.2 mm) to 6.0 in. (152.4 mm)
4	Over 6.0 in. (152.4 mm)

characteristics: groups 03, 02, and 01 for light metals and groups 1 through 5 for heavy metals.

6.2.2 The light metal groups, magnesium (Mg), aluminum (Al), and titanium (Ti), are identified 03, 02, and 01, respectively, for their predominant constituent. The materials are listed in order of increasing radiation absorption.

6.2.3 The heavy metals group, steel, copper base, nickel base, and other alloys, are identified 1 through 5. The materials increase in radiation absorption with increasing numerical designation.

6.2.4 Common trade names or alloy designations have been used for clarification of pertinent materials.

6.3 The materials from which the contrast sensitivity gage is to be made is designated by group number. The gage is applicable to all materials in that group. Material groupings are as follows:

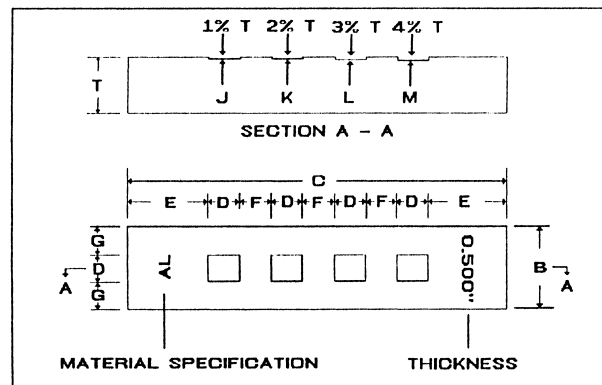


FIG. 1 GENERAL LAYOUT OF THE CONTRAST SENSITIVITY GAGE

6.3.1 Material Group 03:

6.3.1.1 The gage shall be made of magnesium or a magnesium alloy, provided it is no more radio-opaque than unalloyed magnesium, as determined by the method outlined in 6.4.

6.3.1.2 Use for all alloys where magnesium is the predominant alloying constituent.

6.3.2 Materials Group 02:

6.3.2.1 The gage shall be made of aluminum or an aluminum alloy, provided it is no more radio-opaque than unalloyed aluminum, as determined by the method outlined in 6.4.

6.3.2.2 Use for all alloys where aluminum is the predominant alloying constituent.

6.3.3 Materials Group 01:

6.3.3.1 The gage shall be made of titanium or a titanium alloy, provided it is no more radio-opaque than unalloyed titanium, as determined by the method outlined in 6.4.

6.3.3.2 Use for all alloys where titanium is the predominant alloying constituent.

6.3.4 Materials Group 1:

6.3.4.1 The gage shall be made of carbon steel or Type 300 series stainless steel.

6.3.4.2 Use for all carbon steel, low-alloy steels, stainless steels, and magnesium-nickel-aluminum bronze (Superston).

6.3.5 Materials Group 2:

6.3.5.1 The gage shall be made of aluminum bronze (Alloy No. 623 of Specification B 150) or equivalent or nickel-aluminum bronze (Alloy No. 630 of Specification B 150) or equivalent.

6.3.5.2 Use for all aluminum bronzes and all nickel aluminum bronzes.

6.3.6 Materials Group 3:

6.3.6.1 The gage shall be made of nickel-chromium-iron alloy (UNS No. N06600) (Inconel). See Specification B 166.

6.3.6.2 Use for nickel-chromium-iron alloy and 18% nickel-maraging steel.

6.3.7 Materials Group 4:

6.3.7.1 The gage shall be made of 70 to 30 nickel-copper alloy (Monel) (Class A or B of Specification B 164) or equivalent, or 70 to 30 copper-nickel alloy (Alloy G of Specification B 161) or equivalent.

6.3.7.2 Use for nickel, copper, all nickel-copper series or copper-nickel series of alloys and all brasses (copper-zinc alloys) and all leaded brasses.

6.3.8 Materials Group 5:

6.3.8.1 The gage shall be made of tin-bronze (Alloy D of Specification B 139).

6.3.8.2 Use for tin bronzes including gun-metal and valve bronze and leaded-tin bronzes.

6.4 Where the material to be examined is a composite ceramic, or other nonmetallic material, or for some reason cannot be obtained to fabricate a gage, an

equivalent material may be utilized, provided it is no more radio-opaque than the test object under comparable penetrating radiation energy conditions. To determine the suitability of a substitute material, radiograph identical thicknesses of both materials on one film using the lowest penetrating radiation energy to be used in the actual examination. Transmission densitometer readings for both materials shall be in the range from 2.0 to 4.0. If the radiographic density of the substitute material is within +15% to -0% of the test material, the substitute material is acceptable.

6.4.1 All contrast sensitivity gages shall be suitably marked by vibro-engraving or etching. The gage thickness and material type shall be clearly marked.

7. Imaging System Performance Levels

7.1 Imaging system performance levels are designated by a two-part measurement expressed as C(%) — U(mm). The first part of the expression C(%) refers to the depth of the shallowest flat-bottom hole that can be reliably and repeatably imaged. The second part of the expression refers to the companion spatial resolution measurement made with a resolution gage expressed in terms of millimeters unsharpness. Where contrast sensitivity is measured for both thin and thick section performance, the performance level is expressed as C_{min}(%)—C_{max}(%)—U(mm).

7.2 Each contrast sensitivity gage has four flat-bottom recesses that represent 1%, 2%, 3%, and 4% of the gage total thickness. The shallowest recess that can be repeatably and reliably imaged shall determine the limiting contrast sensitivity.

7.3 Contrast sensitivity measurements shall be made under conditions as nearly identical to the actual examination as possible. Penetrating radiation energy, image formation, processing, analysis, display, and viewing variables shall accurately simulate the actual examination environment.

8. Contrast Sensitivity Gage Measurement Steps (see Table 1)

8.1 The gage thickness *T* shall be within ±5% of the test object thickness value at which contrast sensitivity is being determined.

8.2 The gage thickness tolerance shall be within ±1% of the gage design thickness *T* or 0.001 in. (0.02 mm), whichever is greater.

8.3 The gage recess depth tolerance shall be within ±10% of the design value for the shallowest recess or 0.001 in. (0.02 mm), whichever is greater.

8.4 The gage recess inside and outside corner radius shall not exceed 0.062 in. (1.80 mm). To facilitate fabrication, the gage may be assembled from three individually machined components: (1) the machined center section containing the 1% *T*, 2% *T*, 3% *T*, and 4% *T* milled slots; (2) the front rail, and (3) the rear rail. The assemblage of the three components forms the complete gage similar to that shown in Appendix X1.

8.5 The gage dimensional tolerances shall be held to within ±0.010 in. (0.25 mm) of the dimensions specified in Table 2.

9. Acceptable Performance Levels

9.1 Nothing in this test method implies a mandatory or an acceptable contrast sensitivity performance level. That determination is to be agreed upon between the supplier and user of penetrating radiation examination services.

9.2 The recess depths specified in Table 1 provide measurement points at 1%, 2%, 3%, and 4% that will accommodate many imaging system configurations. Other contrast sensitivity measurement points may be obtained by placing the gage on a shim made of the gage material. The resulting contrast sensitivity measurement expressed as a percentage is given by the following formula:

$$\% \text{ Contrast} = \frac{R}{T + S} \times 100$$

where:

R = recess depth,

S = shim thickness, and

T = gage thickness.

If other recess depths are required to document radioscopic system performance, special contrast sensitivity gages may be fabricated by changing the recess depths specified in Table 1 to suit the need.

10. Performance Measurement Records

10.1 The results of the contrast sensitivity measurement should be recorded and maintained as a part of the initial qualification and performance monitoring records for the imaging system. Changes in contrast sensitivity can be an early indicator of deteriorating imaging system performance.

11. Precision and Bias

11.1 No statement is made about the precision or bias for indicating the contrast sensitivity of a radioscopic system using the contrast sensitivity gage described by this test method.

12. Keywords

12.1 contrast sensitivity gage; gamma ray; image formation; image processing; image quality indicator; line-pairs per millimeter; penetrating radiation; spatial resolution; X-ray

APPENDIX**(Nonmandatory Information)****X1. ASSEMBLING THE CONTRAST SENSITIVITY GAGE**

X1.1 Suggested method of assembling the contrast

sensitivity gage from a milled center section with front and rear rails attached to form the complete contrast sensitivity gage. The example shown (see Fig. X1.1) is for use with a 0.500 in. thick test object.

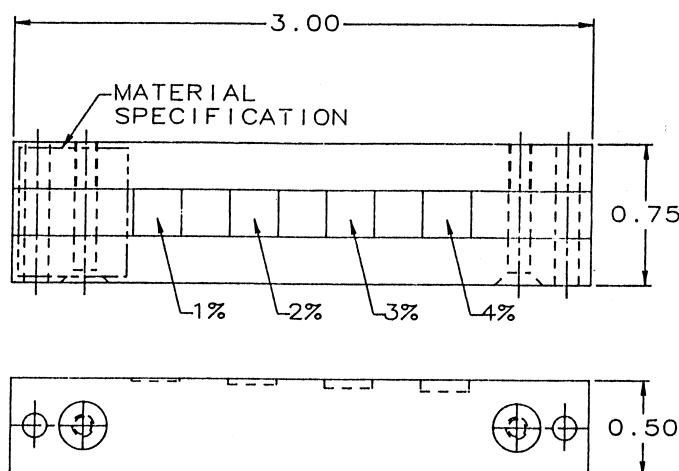


FIG. X1.1 CONTRAST SENSITIVITY GAGE

STANDARD TEST METHOD FOR CLASSIFICATION OF FILM SYSTEMS FOR INDUSTRIAL RADIOGRAPHY



SE-1815



(Identical with ASTM Specification E 1815-96)

1. Scope

1.1 This test method covers a procedure for determination of the performance of film systems used for industrial radiography. This test method establishes minimum requirements that correspond to system classes.

1.2 This test method is to be used only for direct exposure-type film exposed with lead intensifying screens. The performance of films exposed with fluorescent (light-emitting) intensifying screens cannot be determined accurately by this test method.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

- E 94 Guide for Radiographic Testing
- E 999 Guide for Controlling the Quality of Industrial Radiographic Film Processing
- E 1079 Practice for Calibration of Transmission Densitometers
- E 1316 Terminology for Nondestructive Examinations

2.2 ANSI Standards:

- PH 2.18 Photography (Sensitometry) — Density Measurements, Spectral Conditions

- PH 2.19 Photography Density Measurements — Part 2: Geometric Conditions for Transmission Density
- PH 2.40 Root Mean Square (rms) Granularity of Film (Images on One Side Only) Method of Measuring

2.3 ISO Standards:

- ISO 5-2 Photography Density Measurements — Part 2: Geometric Conditions for Transmission Density
- ISO 5-3 Photography Density Measurements — Part 3: Spectral Conditions
- ISO 7004 Photography — Industrial Radiographic Film, Determination of ISO Speed and Average Gradient When Exposed to X and Gamma Radiation

3. Terminology

3.1 Definitions — For definitions of terms used in this test method, refer to Terminology SE-1316.

3.2 Descriptions of Terms Specific to This Standard:

3.2.1 film system — the film and associated film-processing requirements according to the criteria established by the manufacturers of the film and processing chemicals.

3.2.2 gradient G — the slope of the characteristic curve at a certain density, D , and a measure of the contrast of the film system.

3.2.3 granularity, σ_D — the stochastic density fluctuations in the radiograph that are superimposed to the object image.

3.2.4 ISO speed S — determined by the dose K_s , measured in gray at a specified optical density, D , in the radiograph.

TABLE 1
TYPICAL FILM SYSTEM CLASSIFICATION

Automatic Film Processing

Developer: Type A

Developer immersion time: XXX seconds

Developer temperature: XX°C/YY°F

Film Type ⁴	ASTM System Class	Maximum Gradient G at		Maximum Gradient/ Granularity Ratio, G/σ_{D_i} at $D = 2.0$ Above D_o	Maximum Granularity, σ_{D_i} at $D = 2.0$ Above D_o	ISO Speed S	Dose, K_s m Gy, $D = 2.0$
		$D = 2.0$ Above D_o	$D = 4.0$ Above D_o				
A	Special	5.4	9.1	360	0.015	32	29.0
B	I	4.5	8.4	281	0.016	64	14.0
C	I	4.4	7.6	232	0.019	100	8.7
D	I	4.4	7.6	169	0.026	200	4.6
E	II	4.4	7.6	142	0.031	320	3.2
F	III	4.0	5.2	114	0.035	400	2.5
G	W-A	4.2	6.5	225	0.019	100	8.6
H	W-B	4.1	5.3	170	0.025	300	5.0

⁴ Family of films ranging in speed and image quality.

4. Significance and Use

4.1 This test method provides a relative means for classification of film systems used for industrial radiography. The film system consists of the film and associated processing system (the type of processing and processing chemistry). Section 6 describes specific parameters used for this test method. In general, the classification for hard X rays, as described in Section 6, can be transferred to other radiation energies and metallic screen types, as well as screens without films. The usage of film system parameters outside the energy ranges specified may result in changes to a film/system performance classification.

4.1.1 The film performance is described by signal and noise parameters. The signal is represented by gradient and the noise by granularity.

4.1.2 A film is assigned a particular class if it meets all four of the minimum performance parameters: for Gradient G at $D = 2.0$ and $D = 4.0$, granularity σ_D at $D = 2.0$, and gradient/noise ratio at $D = 2.0$.

4.2 This test method describes how the parameters shall be measured and demonstrates how a classification table can be constructed.

4.3 Manufacturers of industrial radiographic film systems will be the users of this test method. The result is a classification table as shown by the example given in Table 1. This table also includes speed data for user information. Users of industrial radiographic

film systems may also perform the tests and measurements outlined in this test method, provided that the required test equipment is used and the methodology is followed strictly.

4.4 The publication of classes for industrial radiography film systems will enable specifying bodies and contracting parties to agree to particular system classes, which are capable of providing known image qualities. See 7.2.

5. Sampling and Storage

5.1 For determination of the gradient and granularity of a film system, it is important that the samples evaluated yield the average results obtained by users. This will require evaluating several different batches periodically, under the conditions specified in this test method. Prior to evaluation, the samples shall be stored according to the manufacturer's recommendations for a length of time to simulate the average age at which the product is normally used. Several independent evaluations shall be made to ensure the proper calibration of equipment and processes. The basic objective in selecting and storing samples as described above is to ensure that the film characteristics are representative of those obtained by a consumer at the time of use.

6. Procedure

6.1 Principle:

6.1.1 Film to be tested shall be exposed to X rays from tungsten target tubes. Inherent filtration of the tube, plus an additional copper filter located as close to the target as possible, shall provide filtration equivalent to 8.00 ± 0.2 mm of copper.

6.1.2 The film system includes a front and a back screen of 0.02 to 0.25-mm lead. If single-coated films are used, the emulsion-coated surface must face the X-ray tube. Vacuum or pressure cassettes may be used to ensure sufficient contact between the film and screen.

6.2 X-ray Spectral Quality:

6.2.1 Use the same X-ray spectral quality for determining both the film gradient and its root mean square granularity. Make the film exposures with an 8-mm (0.32-in.) copper filter at the X-ray tube and the kilovoltage set such that the half value layer in copper is 3.5 mm (0.14 in.). The kilovoltage setting will be approximately 220 kV.

6.2.2 Determine the required kilovoltage setting by making an exposure (or exposure rate) measurement with the detector placed at a distance of at least 750 mm (29.5 in.) from the tube target and an 8-mm (0.32-in.) copper filter at the tube. Then make a second measurement with a total of 11.5 mm (0.45 in.) of copper at the tube. These filters should be made of 99.9% pure copper.

6.2.3 Calculate the ratio of the first and second readings. If this ratio is not 2, adjust the kilovoltage up or down and repeat the measurements until a ratio of 2 (within 5%) is obtained. Record the machine setting of the kilovoltage for use with the film tests.

6.3 Film Cassette and Screens:

6.3.1 The film cassette (holder) shall provide a means of ensuring good film screen contact. A vacuum cassette may be used.

6.3.2 Lead-foil screens shall be used with the front screen thickness being 0.130 ± 0.013 mm (0.005 ± 0.05 in.) and the back screen thickness being 0.250 ± 0.025 mm (0.010 ± 0.001 in.).

NOTE — These thicknesses reflect commercially available tolerances in lead foil for use as radiographic screens.

6.3.3 It is especially important that the exposure to the film specimen for the granularity measurements be spatially uniform. Any nonuniformities in X-ray

transmission of the cassette front or nonuniformities or defects in the lead-foil screens could influence the granularity measurement. Therefore, exercise considerable care in selection and maintenance of the cassette and lead screens to minimize these effects.

6.3.4 Expose single-coated films with the emulsion-coated surface in contact with the front screen.

6.4 Film Processing — The film image quality will vary with the processing variables, such as chemistry, temperature, and method of processing (manual or automatic). The film processing and record requirements shall be in accordance with Guide E 999.

6.5 Exposure Conditions:

6.5.1 The plane of the film shall be normal to the central ray of the X-ray beam. Use a diaphragm at the tube to limit the field of radiation to the film area. The X-ray tube target to film distance shall be adequate to ensure that the exposure over the useful area of each exposure step is uniform to within 3%.

6.5.2 To minimize the effects of backscattered radiation, use a 6.3 ± 0.8 mm ($\frac{1}{4} \pm \frac{1}{32}$ in.) thick lead shielding behind the cassette. The shielding lead shall extend at least 25 mm (1 in.) beyond each edge of the cassette. Alternatively, the shielding lead may be omitted, provided that the cassette is supported such that the X-ray beam strikes no scattering material, other than air, for a distance of at least 2 m (78.7 in.) behind the cassette.

6.5.3 Modulation of the X-ray exposure may be accomplished by changing the exposure time or tube target to film distance. Changing the tube current is not recommended but may be done, provided it is verified by measurement (see 6.2) that the X-ray spectral quality does not change.

6.5.4 Measure exposures with an air-ionization chamber, or other types of X-ray detectors, having linear response over the range of X-ray intensities and exposure times used for the film exposures.

6.5.5 During and after exposure, prior to processing, keep the film at a temperature of $23 \pm 5^\circ\text{C}$ ($5.97 \pm 5^\circ\text{F}$) and a relative humidity of $50 \pm 20\%$. Start processing of the film between 30 min and 8 h after exposure. Process an unexposed specimen of the film sample with the X-ray-exposed specimen in order to determine the base plus fog density.

6.5.6 Measure the visual diffuse transmission density of the processed films with a densitometer complying with the requirements of ANSI PH 2.19 and ISO

5-2 and calibrated by the method of Practice E 1079. Use a minimum aperture of 7 mm (0.275 in.).

6.6 Measurement of Gradient G :

6.6.1 Gradient G relates to a D versus $\log K$ curve. In the scope of this test method, G is calculated from the slope of a D versus K curve at density ($D - D_o$), as follows:

$$G = \frac{dD}{d \log K} = \frac{K}{\log e} \times \frac{dD}{dK}$$

where:

K = dose required for density $D - D_o$, and
 D_o = fog and base density.

6.6.2 The D versus K curve is approximated by a polynomial of the third order. To obtain a regular and reliable shape of this curve, make a series of exposures to obtain at least 12 uniformly distributed measuring points between density 1.0 and 5.0 above D_o .

6.6.3 Average the Gradient G measurements, with a maximum inaccuracy of $\pm 5\%$.

6.7 Root Mean Square (rms) Granularity, σ_D :

6.7.1 Determine the rms granularity of the film in accordance with ANSI PH 2.40, with the following exceptions:

6.7.2 The procedure is limited to the measurement of continuous tone black-and-white industrial X-ray films viewed by transmitted light. The film may have emulsion coated on one side or both sides of the film support.

6.7.3 Expose the film specimen with X rays having the spectral quality described in 6.2. The cassette and lead-foil screens shall be as specified in 6.3. Expose the film specimen in accordance with the exposure conditions of 6.5. Exercise care to ensure that the film specimen does not contain density variations arising from the exposing equipment (such as nonuniform beam filters or damaged or defective lead screens). During and after exposure, prior to processing, maintain the film specimen at the temperature and relative humidity conditions specified in 6.5.5. The film processing chemicals and procedures shall be the same as those used for determining gradient, and they shall be described completely as specified in 6.4.

6.7.4 The film specimen for granularity measurement shall have a diffuse density of 2.00 ± 0.05 above base plus fog. As an alternative, three or more samples of the film specimen at different density levels, within

the range from 1.80 to 2.20, may be measured, and the granularity value at a diffuse density of 2.00, above base plus fog, shall be taken from a smooth curve drawn through a plot of the data points. The granularity value shall be in terms of diffuse density.

6.7.4.1 The microdensitometer scanner output is measured as projection density. Thus to obtain the desired diffuse density, convert the data using the slope of the curve of diffuse density versus projection density at the mean density value of the granularity film specimen. Determine this curve using a film having a stepped series of densities, which is prepared using the same type film, exposure, and processing techniques as used for the granularity film specimen. Measure the diffuse density of each step with a microdensitometer. The specimen film shall be scanned using identical microdensitometer settings. A limited range of densities can typically be measured for a given microdensitometer gain setting. The stepped series of densities shall lie within that range. Choose the number of steps such that the slope of the curve, at the mean density of the granularity film specimen, is determined to an accuracy of $\pm 5\%$.

6.7.5 Determine the granularity of the film specimen by evaluating no fewer than three samples of the specimen and determining their mean so that a maximal uncertainty of 10% is achieved.

6.7.6 Adjust the optical system of the microdensitometer so that both emulsions, or the one emulsion in the case of a single-coated film, are in focus at all points in the scan.

6.7.7 Scan the film specimen along three different paths within the test area. Take the median of the three granularity readings as the granularity of the film specimen at the mean measured density.

6.7.8 Microdensitometer Requirements:

6.7.8.1 The influx aperture of the microdensitometer shall be approximately circular in shape, with a diameter (referred to the plane of the specimen) not less than $1.2\times$ or more than $2\times$ the diameter of the efflux aperture.

6.7.8.2 Both the influx objective and the efflux objective shall be a high-quality microscope objective having a numerical aperture no greater than 0.10.

6.7.8.3 The reduction of the influx aperture by the influx optics and the magnification of the specimen onto the efflux aperture by the efflux optics shall lie

TABLE 2
DETERMINATION OF ISO SPEED S FROM DOSE, K_s ,
NEEDED FOR A FILM DENSITY, $D = 2.0$, ABOVE D_o

$\log_{10} K_s$		ISO Speed S ^A
From	To	
-3.05	-2.96	1000
-2.95	-2.86	800
-2.85	-2.76	640
-2.75	-2.66	500
-2.65	-2.56	400
-2.55	-2.46	320
-2.45	-2.36	250
-2.35	-2.26	200
-2.25	-2.16	160
-2.15	-2.06	125
-2.05	-1.96	100
-1.95	-1.86	80
-1.85	-1.76	64
-1.75	-1.66	50
-1.65	-1.56	40
-1.55	-1.46	32
-1.45	-1.36	25
-1.35	-1.26	20
-1.25	-1.16	16
-1.15	-1.06	12
-1.05	-0.96	10
-0.95	-0.86	8
-0.85	-0.76	6
-0.75	-0.66	5
-0.65	-0.56	4

^A See ISO 7004.

in the range from 20 to 100 $\times$. The two magnifications need not be equal.

6.7.8.4 The efflux (or measuring aperture) shall be circular in shape. Its effective diameter referred to the specimen plane shall be $100 \pm 2 \mu\text{m}$.

6.7.8.5 The scan path of the microdensitometer may be linear or circular. If circular, the radius of the path shall not be less than 16 mm. In either case, the total scan length shall not be less than 100 mm (3.94 in.).

6.7.8.6 The spectral response of the microdensitometer system shall be visual, as specified by ANSI PH 2.18 and ISO 5-3.

6.7.8.7 The electronic band-pass filter, used to reduce the unwanted signal caused by system artifacts, shall have its low-frequency boundary set so the system response is 3 dB down at a temporal frequency corresponding to a spatial frequency of 0.1 cycles/mm. Its high-frequency boundary shall be set so that the system response is 3 dB down at a temporal frequency corresponding to the first zero in the spatial frequency response of the circular aperture. Mathematical procedures that can be shown to produce equivalent reductions in the effects of system artifacts are acceptable alternatives to the use of this filter.

TABLE 3
LIMITING VALUES FOR GRADIENT, GRADIENT/
GRANULARITY RATIO, AND GRANULARITY

ASTM System Class	Minimum Gradient G at		Minimum Gradient/ Granularity Ratio, G/σ_D at $D = 2.0$ Above D_o	Maximum Granularity, σ_D , at $D = 2.0$ Above D_o
	$D = 2.0$ Above D_o ^A	$D = 4.0$ Above D_o		
Special	4.5	7.5	300	0.018
I	4.1	6.8	150	0.028
II	3.8	6.4	120	0.032
III	3.5	5.0	100	0.039
W-A	3.6	5.7	135	0.027
W-B	3.5	5.0	110	0.032
W-C	<3.5	<5.0	80	0.039

^A D_o = density of an unexposed and processed film including base (fog and base density).

6.8 Measurement of ISO Speed S — The ISO Speed S is evaluated for an optical density, $D = 2.0$, above fog and base, D_o . Use Table 2 for determination of the ISO speed.

7. Range of Classification and Limiting Values

7.1 There are film system classes that differ by their gradients and granularities. The limiting values are assigned to the film classes whose observance must be proved by the measuring methods in 6.6 and 6.7.

7.1.1 In order to assign a film system to a system class, it must meet all four limiting values of the gradient (at $D = 2.0$ and $D = 4.0$), the granularity (at $D = 2.0$), and the gradient/granularity parameter of the system class. The classification is valid only for the complete film system.

7.2 Film system manufacturers will provide their classification table, upon request, with a classification table that contains full data on the four parameters according to Table 3. In addition, the following two parameters (see Table 2 for data) will be listed with the classification table: ISO speed S, and dose, K_s .

7.2.1 The classification table will additionally contain the following information on the processing system:

manual or automatic, type of chemistry, developer immersion time, and developer temperature.

7.3 For examples of a classification table, see Table 1.

8. Precision and Bias

8.1 No statement is made about either the precision or bias of this test method for measuring a film system

classification of industrial radiographic film since the results state merely whether there is conformance to the criteria for success specified in the procedure.

9. Keywords

9.1 ASTM system class; film system; film system classification; gradient; gradient/noise; granularity; industrial radiographic film; speed.

APPENDIX

(Nonmandatory Information)

X1. GENERAL PRINCIPLES OF CLASSIFICATION

X1.1 The purpose of this test method is to classify industrial radiographic film systems based on their image quality performance over the practical working range of densities (for example, from 2.0 to 4.0). The classes are differentiated in image quality performance based on limiting values for four measurable image quality parameters, that is, gradient at density 2.0 and 4.0 and granularity and gradient/granularity ratio at density 2.0. See Table 3.

X1.1.1 The result of classification can be documented in a table with the following details:

X1.1.1.1 Description of the film system (film and processing),

X1.1.1.2 Values for four image quality parameters and the corresponding system class, and

X1.1.1.3 Speed of the film system.

X1.1.2 The optimal film system based on system classification (imaging performance) and speed (exposure time) can be selected with this information. See Table 1 for an example.

X1.2 Significance of Classes

X1.2.1 Various codes and specifications require film selection based on a class (Type 1, 2, or 3) from a version of Guide E 94 dated before 1984. In Guide E 94-83, speed, contrast, and graininess were specified as limiting values, but only in a subjective way. According to this guide, a range of films was classified in order of increasing speed and decreasing image

quality (contrast and graininess). Image quality was optimized for a given speed.

X1.2.2 This test method has similar classes: Special, I, II, and III (see Table 3). The film systems that will generally fit this classification are of high-contrast technology. Image quality is optimized for every speed. Granularity increases with speed, and gradient is a maximum for the slower speed film systems.

X1.2.3 The slower film systems give the highest image quality, through a combination of low granularity and high gradient for both Density 2.0 and 4.0 and a corresponding high gradient/granularity ratio.

X1.2.4 Four classes of this test method were selected to correspond to the former film classification standard table of Guide E 94-83. See Table X1.1.

X1.2.5 Table X1.2 provides classification of wide latitude film systems. In comparison to traditional high-contrast technology, these film systems are generally characterized by a lower gradient for a given speed, producing wider exposure latitude and correspondingly lower image quality. The gradient will be lower at density 2.0 and significantly lower at high densities. Limiting values for image quality parameters are as follows (classes of wide-latitude film systems do not correspond directly to classes of former Guide E 94-83):

X1.2.6 The wide-latitude system classes are described as follows:

X1.2.6.1 *W-A and W-B* — Films with ASTM System Class III or better image quality. In general, these films use intermediate technology (between traditional high contrast and low contrast). Applications are judged by comparing all four image quality parameters.

TABLE X1.1
CLASSIFICATION COMPARISON OF TEST METHOD E 1815 AND GUIDE E 94-83 FOR HIGH-CONTRAST FILM SYSTEMS

Test Method SE-1815 System Class	Minimum Gradient G at		Minimum Gradient/ Granularity Ratio at $D = 2.0$	Maximum Granularity at $D = 2.0$	Guide E 94-83 Film Type	Description		
	$D = 2.0$	$D = 4.0$				Speed	Contrast	Graininess
Special	4.5	7.5	300	0.018				
I	4.1	6.8	150	0.028	1	Low	Very high	Very low
II	3.8	6.4	120	0.032	2	Medium	High	Low
III	3.5	5.0	100	0.039	3	High	Medium	High

X1.2.6.2 W-C — Film systems with lower image quality performance than ASTM System Class III. In general, this is low-contrast (medical) film technology in combination with direct exposure technique.

NOTE X1.1 — The combination of Tables X1.1 and X1.2 corresponds to Table 3.

NOTE X1.2 — Fundamental differences between this test method and Guide E 94-83 are as follows: (1) with this test method, film systems are classified instead of film types (as in Guide E 94-83); and (2) in this test method, classification is based only on imaging performance. Speed is not a classification parameter.

TABLE X1.2
TEST METHOD E 1815 CLASSIFICATION OF WIDE-LATITUDE FILM SYSTEMS

Test Method SE-1815 Film System Class	Min. Gradient G at		Min. Gradient/ Granularity Ratio, G/σ_D , at $D = 2.0$ Above D_o	Max. Granularity, σ_D at $D = 2.0$ Above D_o
	$D = 2.0$ Above D_o	$D = 4.0$ Above D_o		
W-A	3.8	5.7	135	0.027
W-B	3.5	5.0	110	0.032
W-C	<3.5	<5.0	80	0.039

SI UNITS

The 2001 Edition of the Boiler and Pressure Vessel Code is based on U.S. Customary (ft-lb) units of measurement which are to be regarded as the standard. This supplement is provided as a convenience to the Code user and contains SI conversion factors for units contained in the Code.

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

Quantity	Unit	Symbol	Other Units or Limitations
Space and Time			
plane angle	radian	rad	degree (decimalized)
length	meter	m	
area	square meter	m ²	
volume	cubic meter	m ³	liter (L) for liquid only (use without prefix other than in milliliter, mL)
time	second	s	minute (min), hour (h), day (d), week, and year
Periodic and Related Phenomena			
frequency	hertz	Hz	revolutions per second (r/s)
rotational frequency	revolutions per second	s ⁻¹	revolutions per minute (r/m)
Mechanics			
mass	kilogram	kg	
density	kilogram per cubic meter	kg/m ³	
moment of inertia	kilogram · meter ²	kg · m ²	
force	newton	N	
moment of force (torque)	newton-meter	N · m	
pressure and stress	pascal	Pa	(pascal = newton per square meter)
energy, work	joule	J	kilowatt-hour (kW · h)
power	watt	W	
impact strength	joule	J	
section modulus	meter ³	m ³	
moment of section (second moment of area)	meter ⁴	m ⁴	
fracture toughness	Pa · $\sqrt{\text{m}}$		
Heat			
temperature — thermodynamic [Note (2)]	kelvin	K	degree Celsius (°C)
temperature — other than thermodynamic	degree Celsius	°C	kelvin (K)
linear expansion coefficient	meter per meter-kelvin	K ⁻¹	°C ⁻¹
quantity of heat	joule	J	
heat flow rate	watt	W	
thermal conductivity	watt per meter-kelvin	W/(m · K)	W/(m · °C)
thermal diffusivity	square meter per second	m ² /s	
specific heat capacity	joule per kilogram-kelvin	J/(kg · K)	J/(kg · °C)
Electricity and Magnetism			
electric current	ampere	A	
electric potential	volt	V	
current density	ampere per meter ²	A/m ²	
magnetic field strength	ampere per meter	A/m	

NOTES:

- (1) Conversion factors between SI units and U.S. customary are given in SI-1, "ASME Orientation and Guide for Use of SI (Metric) Units," and ASTM E 380.
- (2) Preferred use for temperature and temperature interval is degrees Celsius (°C), except for thermodynamic and cryogenic work where kelvins may be more suitable. For temperature interval, 1 K = 1°C exactly.

COMMONLY USED CONVERSION FACTORS
(For Others See ASTM E 380) [See Note (1)]

Quantity	To Convert From	To	Multiply by [Note (2)]	
plane angle	degree	rad	1.745 329	E-02
length	in	m	2.54*	E-02
	ft	m	3.048*	E-01
	yd	m	9.144*	E-01
area	in ²	m ²	6.451 6*	E-04
	ft ²	m ²	9.290 304*	E-02
	yd ²	m ²	8.361 274	E-01
volume	in ³	m ³	1.638 706	E-05
	ft ³	m ³	2.831 685	E-02
	US gallon	m ³	3.785 412	E-03
	Imperial gallon	m ³	4.546 09	E-03
	liter	m ³	1.0*	E-03
mass	lbm	kg	4.535 924	E-01
	ton (metric) (mass)	kg	1.000 00*	E+03
	ton (short 2000 lbm)	kg	9.071 847	E+02
force	kgf	N	9.806 65*	E+00
	lbf	N	4.448 222	E+00
bending, torque	kgf · m	N · m	9.806 65*	E+00
	lbf · in	N · m	1.129 848	E-01
	lbf · ft	N · m	1.355 818	E+00
pressure, stress	kgf/m ²	Pa	9.806 65*	E+00
	lbf/ft ²	Pa	4.788 026	E+01
	lbf/in ² (psi)	Pa	6.894 757	E+03
	kips/in ²	Pa	6.894 757	E+06
	bar	Pa	1.0*	E+05
energy, work	Btu (IT) [Note (3)]	J	1.055 056	E+03
	ft · lbf	J	1.355 818	E+00
power	hp (550 ft · lbf/s)	W	7.456 999	E+02
fracture toughness	ksi $\sqrt{\text{in}}$	Pa · $\sqrt{\text{m}}$	1.098 843	E+06
temperature	°C	K	$t_K = t_C + 273.15$	
	°F	K	$t_K = (t_F + 459.67)/1.8$	
	°F	°C	$t_C = (t_F - 32)/1.8$	
temperature interval	°C	K	1.0*	E+00
	°F	K or °C	5.555 555	E-01

NOTES:

- (1) Care should be taken when converting formulas or equations that contain constant terms or factors. The value of these terms must be understood and may also require conversion.
- (2)(a) Relationships that are exact in terms of the base units are followed by a single asterisk.
- (b) The factors are written as a number greater than 1 and less than 10 with 6 or less decimal places. The number is followed by the letter E (for exponent), a plus or minus symbol, and two digits which indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example: 3.523 907 E-02 is $3.523\ 907 \times 10^{-2}$ or 0.035 239 07.
- (3) International Table

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